Nexus Outlook

"Assessing international challenges"

ITT
Institute for Technology and Resources Management in the Tropics and Subtropics

Technology Arts Sciences TH Köln

Nexus
Water | Energy | Food Security

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Nexus Outlook

Assessing resource use challenges in the water, energy and food nexus

Editors:

Mohammad Al-Saidi

Lars Ribbe

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Foreword

Debates in environmental science and policy reflect transformation processes which societies undergo as as a result of interactions with nature. The 'nexus debate' on water, energy and food security is one recent example of how we react to the societal demand for knowledge-based solutions for today's problems. With ever increasing demands for water, energy and food supplies, our production systems of natural resources are under pressure to deliver. Without alternative sources and improving resource use efficiencies, we will be using more of one resource to produce another, leading to increasing interlinks and unforeseen impacts. The integrative vision of the nexus is to provide solutions to achieve the securities of water, energy and food while at the same time considering interdependent relations and impacts. Such endeavour begins with analysing the status quo of resources use and identifying threats and unstainable patterns. The 'nexus outlook' report presents a range of case studies covering extensive and synthesized status-quo assessments from eight case studies in Latin America, Africa and Asia. With this broad range, we acquire a good insight of common challenges of the nexus like the quantification of the natural resources interlinks, the identification of unsustainable thresholds and the development of adequate cross-sectoral governance systems.

By bringing together scientists and practitioners to present the 'nexus perspective' from their case studies,a variety of issues associated with the nexus become evident. The presented studies were not based on a common methodology or a uniform understanding of the nexus. The plurality of nexus interpretations allows for creativity in the presentation of important challenges and needed reform priorities. I express my gratitude and appreciation to all participating authors and the team behind this publication. Together, we show that our joint work in various nexus-related projects is valuable, and the integration of water, energy and land issues in natural resources management is our common challenge.

The 'nexus report' constitutes an initial investigation of nexus-related research topics across various regions representing the collaboration of partner countries in in different projects and professional partnerships. The report is a product facilitated by the Nexus Research Focus of the TH-Köln – University of Applied Science. It also includes references to undergoing since 2013 with co-funding from the Ministry for Innovation, Science and Research of the State of North Rhine-Westphalia. We would like to express our thanks and gratitude for this support via research funding and research-related mobility. Future nexus related work can address some of the identified research issues in this report, which builds a promising basis for regional and cross-regional project-based research cooperation.

Prof. Dr. Lars Ribbe

Speaker of the Nexus Research Focus

Director of the ITT

Ethiopian Dawn, by A. Davey

Introduction to Nexus Outlook

At its core, 'nexus outlook' is a collection of case studies which aims at providing a cross-regional picture of common nexus challenges across the world. A central theme in the report is the issue of assessing nexus interlinks and challenges in different contexts. The report allows for different authors to present nexus issues in different case studies using indicators of their choice. At the same time, it tries to synthesize the evolvement of the next issue in different regions and to propose nexus assessments ranging from rapid assessments to detailed analyses.

The first part ,'nexus assessment', provides a concise introduction to the integration idea of the nexus and highlights key insights that differentiate this new paradigm from previous integration discussions in natural resources management. At the same time, an introduction to the use, usefulness and developmental steps of nexus-relevant assessments is provided, and examples from previous research are given. The second part ,'nexus in-depth', introduces two case studies (Chile and Vietnam) with a more detailed look at recent pressures on natural resources and the evolvement of nexus issues. These two studies, commissioned by the Nexus Research Focus through mobility support for PhD students, represent two countries undergoing tremendous transitions in resource use patters due to growing internal demands and increased integration into global markets. The third part ,'nexus snapshots', includes highlights on nexus challenges from six different case studies around the world. The case studies contributed to an international gathering on the nexus topic held at the Institute for Technology and Resources Management in the Tropics and Subtropics (ITT) in July 2016. In order to mainstream some results, each case study ends with a 'nexus timeline' summarizing the evolvement of issues in a historical perspective. The printed version of the 'nexus report' also includes the 'nexus country profiles' as an elaborate nexus assessment methodology developed by the Nexus Research Focus in recent years. These profiles summarize, using a limited set of indicators and infographics, the nexus issues in a certain country and introduce a 'nexus rapid assessment', rating nexus challenges in the country. The profiles have been applied to the Eastern Nile countries of Ethiopia, Egypt and Sudan while other profiles for Nepal and Vietnam are under still under production.

The 'nexus report' was initiated within the Nexus Research Focus of the TH Köln – University of Applied Sciences, as a research based product which serves different purposes. Apart from showing projects and work related to the research focus, it is also linked to the development of a master-level 'Nexus Module' under production. The module includes key slides, selected literature and sheets with key facts covering an introduction to the nexus paradigm, nexus governance, nexus modelling and nexus governance. These materials developed for the module will be shared with partner universities and used in current university courses. With this, we express our gratitude for all participants in many activities and projects related to the water, energy, and food nexus which have produced many valuable products.

Dr. Mohammad Al-Saidi

Coordinator of the Nexus Research Focus

Nexus Assessments

Introduction to the Integration Idea of the Nexus

Nexus as Buzzword and Sustainability Debate

Since the World Economic Forum gathering in 2011 and the Bonn Conference in the same year, the Water, Energy food Nexus (WEF Nexus) is at the forefront of environmental policy debates. More than 300 publications since 2009 and numerous international or regional gatherings have reiterated the core idea that the security of three natural resources are highly interdependent. Such interdependence is empirical. It is evident in the increasing quantities of natural resources which we need to produce more of other resources. Economic growth and demographic changes like urbanization and changing lifestyles together with external drivers like climate change will increase societies' demand for water, food and energy. Global demands for food and energy are expected to increase by 50% and for freshwater by 30% in the year 2015 (Beddington in Leck et al. 2015). In order to accommodate for these basic future requirements, societies resort, for example, to building large dams and cultivating more land for biofuels and food production. These solutions come along with inherent trade-offs in terms of which resource security should be given the priority. In the same line, can we develop better solutions which do not compromise the security of one resource for the sake of securing another one?

The WEF Nexus emerged as a necessary reaction to the failures of sector-driven management strategies. It represents the current need to engage in knowledge-based debates about the consequences of increasing interlinks among natural resources and the tools to improve the securities of water, energy and food at the same time. The presumption is that academia and policymaking lack an 'integrated view' on use issues of natural resources. With the WEF Nexus, the 'sensibility' for the importance of such integration as well as the 'means' to achieve this integration can be created. Recent supply crises reminded many practitioners of the need for integrated planning. When drought hit China in 2010 and 2011, local food production and hydropower generation were negatively affected, leading to a surge in food prices and unrest in many other countries (Bleischwitz et al., 2014). Similarly, several heatwaves in Europe led to crop failures and a lack of cooling water for nuclear power production (Olsson, 2013). The realization of the vulnerability of our loosely integrated resource production systems highlights the value of the WEF Nexus debate. Not surprisingly, such debate is positively received in academic literature despite being also titled a popular "buzz word" (e.g. Stein et al. 2014) and also a "mercurial concept" (Bell et al. 2016) under evolvement.

Citation: The WEF Nexus represents the current need to engage in knowledge-based debates about the consequences of increasing interlinks among natural resources and the tools to improve resource security. Mohammad Al-Saidi and Lars Ribbe

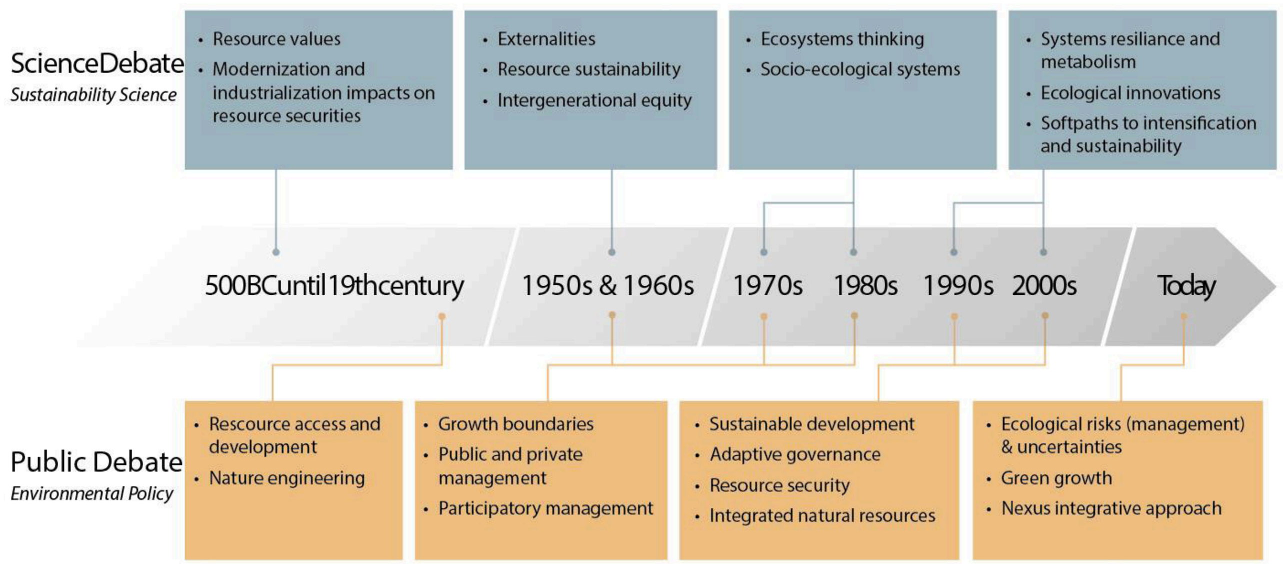


Figure : Precursors of Nexus in sustainability science
Source: Precursors of the Nexus according to Al-Saidi and Elagib (2017)

Integrated Management and the Nexus

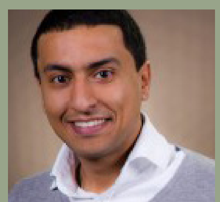
Integration is one core proposition of the various versions of the WEF Nexus. In this sense, the WEF Nexus follows the tradition of the ecological economics and systems thinking which originated in the 1980s and 1990s. During this period, many suggestions to achieve such integration in different sectors were put forward. Different integrated management concepts were formulated as, for example, the Integrated Water Resources Management or IWRM. In fact, IWRM is a direct relative to the WEF Nexus paradigm. It stressed the importance of integrating policies in different water sub-sectors and linking water management issues to neighboring sectors like land. There are some scientists who attribute the emergence of the WEF Nexus idea to failures of IWRM to achieve its holistic agenda (e.g. Muller 2015). Others stress the fact that water is the key resource within the WEF Nexus (e.g. Perrone and Hornberger 2014 and Beck and Walker 2013). Regardless, one can observe a relatively high involvement of water scientists in the Nexus debate. The water centrality in the WEF Nexus debate is not surprising because it is the natural resource through which many pressures manifest themselves and are transformed, e.g. droughts, floods, storms, pollution etc. Regions with high water availability are better positioned to achieve energy and food security with fewer trade-offs. Increasing regional water scarcity is often the reason behind increased interdependence and more frequent supply crises. Previous concepts of integrated management in natural resources emphasized this notion of interdependence of different resource uses and promoted interdisciplinarity in management practices. The WEF Nexus as an integrated management paradigm extends these claims to highlighting the intersectorality of natural resources use issues and the interactionality of impacts of resources allocations (Al-Saidi and Elagib 2017). With this, the focus shifts from sectoral integrated management to cross-sectoral coordination in policymaking and day-to-day management decisions.

Key Insights of the New Paradigm

The WEF Nexus builds the current state of knowledge in environmental policy and relates it to the key idea of integrated water, energy and food management. In doing so, it reiterates some insights about the way forward to achieve more integration in the management of natural resources. First, the Nexus agenda often stresses the importance of developing comprehensive cross-sectoral assessments with regard to certain resource use issues, e.g. resources use within a basin. Such comprehensive assessments go beyond the holistic planning concepts often propagated for natural resources which were often sectoral, e.g. via a detailed national water strategy. The idea behind comprehensive assessments is that one should consider resource planning across sectors and capture as many interlinks and impacts as possible. Second, methods like integrated modelling or trade-off analysis can serve to capture the envisioned integration of the WEF Nexus. Such methods go beyond the often one-directional analyses to capture use externalities or impacts. Further, an important element of the nexus debate is how to move beyond stakeholder participation related to a project or sector plan towards the establishment of multi-stakeholder platforms with broad, cross-sectoral participation. This means the inclusion of stakeholders like powerful private agricultural producers, big energy suppliers or water basin representatives into one platform. Until now, discussions related to the WEF Nexus have been most effective in steering such kind of debates about the merits of integrated thinking among various stakeholders. Finally, WEF Nexus reiterates state of the art concepts like eco-innovations and risk management. Such concepts distinguish themselves from older ideas about resource use efficiencies or crisis management. In a strict sense, eco-innovations imply any technology, organizational or institutional method which positively redefines the way we produce and consume water, energy or food for example. Such innovations should ultimately improve resource use efficiency but also other aspects related to the environmental friendliness of production in general. In a similar way, risk management extends the concepts' crisis management by putting the focus on prevention, preparedness and risk analysis. Similar to eco-innovations, risk management brings a new and important emphasis which suits current management needs. The WEF Nexus idea adopted many of such new ideas in its debates about the goals of integration among the three resources. This way, the WEF Nexus does not become a rigid concept but rather an open debate about sustainability pathways in natural resources.

Citation: Discussions related the WEF Nexus have been most effective in steering debates about the merits of integrated thinking among various stakeholders. Mohammad Al-Saidi and Lars Ribbe

Authors



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Development and Use of Nexus Assessments

Use and Merits of Sustainability Assessments

Sustainability has been a major concern of policymakers and scientists alike since the second half of the last century. In order to define solutions to address unsustainable trends in the use of natural resources like water, energy or land, assessment tools are widely used. Sustainability assessments are basically quantifications or evaluations based on expert knowledge of a pre-defined conceptualization of a sustainability understanding. With this, sustainability assessments will largely depend on how we define the term 'sustainable' and on the issue to which we relate it. To explore this further, one can differentiate between four different understandings of sustainability in environmental sciences. 'Intervention sustainability' is basically an evaluation of specific set of actions, e.g. development project, new environmental policy or management decision. This understanding represents the most original understanding of sustainability, namely the continuation of benefits beyond the lifespan of intervention. It conveys limited issues and a small timeframe for assessment. 'Resource sustainability' looks at the use and resulting impacts of a certain natural resource (e.g. water), including issues like integration of decisions, protection of non-renewable resources, intergenerational equity etc. In contrast, environmental sustainability is a broader term which relates sustainability to environmental issues at large, i.e. an evaluation of the footprint societies leave on the environment or natural resources in general. Sustainability assessments related to the water, energy and food nexus can deploy one of the two latter understandings. Depending on the perspective, nexus-specific assessments can look at sustainability from the point of view of one sector, e.g. water resource sustainability considering influence of energy and land issues. Alternatively, there are assessments that integrate all three issues into one system and that even extend the issues to the effects on eco-systems, biodiversity or climate. They can thus be seen in this tradition of debating environmental sustainability as a whole. Finally, 'sustainable development' is the most encompassing understanding of sustainability as it relates the concept of sustainability to the underlying growth and development model of societies. 'Environmental sustainability' is then only a pillar of sustainable development which commonly also includes economic efficiency and social equity. This has been the understanding of sustainable development for almost 30 years now.

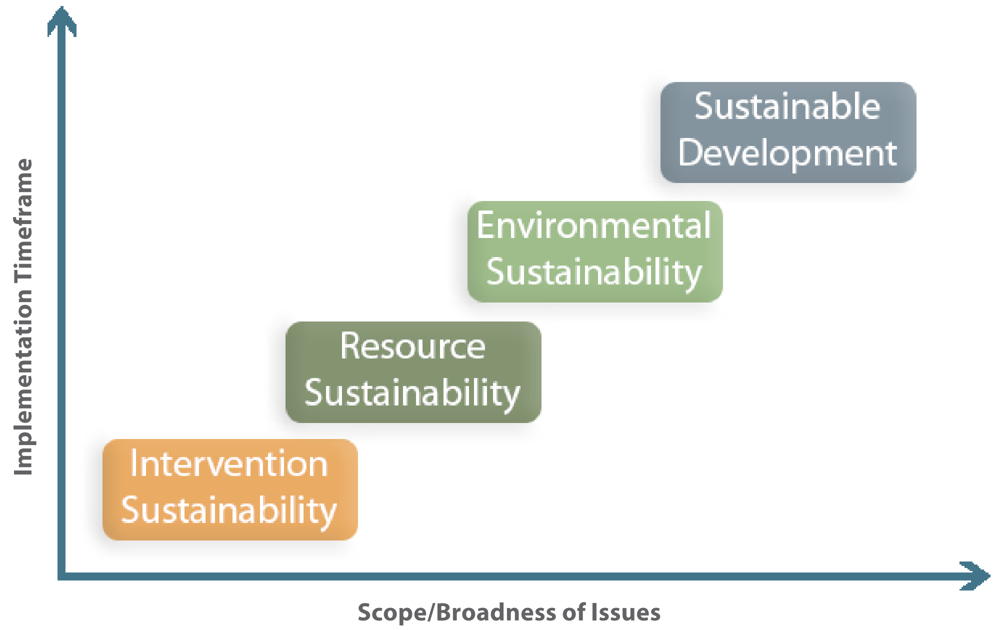


Figure 1: Sustainability understandings in environmental sciences

Sustainability assessments help operationalize the normative vision of living or growing within our reasonable means. In developing such assessments, one has to define certain elements before applying them to examine the issues. The 'needs' of the assessments represent the responses to the problematic situation under evaluation. It entails the ultimate contribution of the assessment. Often, sustainability assessments about topics like the nexus interactions contribute to formulating measures which enhance sustainable development at large. Further, the 'purpose' of the assessment is its specific focus, e.g. emphasizing future or past trends, showing stakeholder perceptions or evaluating ecological thresholds etc. It thus determines the 'methods' of the assessment. There are a wide variety of assessment methods ranging from indicator- or index-based to perception-based when using surveys, expert knowledge or panel judgements. Developing such assessments is not always easy. It includes many other intermediate steps like developing a conceptual model, evaluating the validity and measurability of indicators or evaluating data quality and availability (see here the assessment framework of the WWAP 2003).

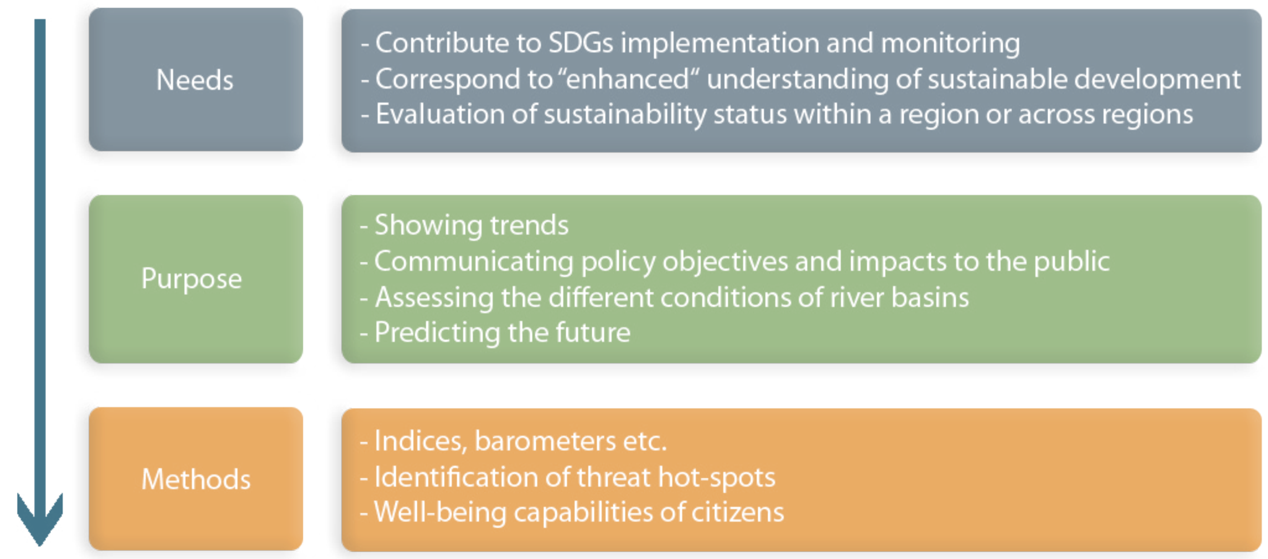


Figure 2: Steps and examples in developing sustainability assessment

Nexus-Specific Assessments at Different Scales

Nexus-specific assessments are of high need due to the high relevance of the topic in current environmental policy. A wide variety of assessments looking at nexus interactions can be developed, depending on the selection of issues and case study needs. There is also a need for comparative cross-regional nexus assessments because they offer an opportunity for mutual learning and evaluating different nexus-relevant sustainability pathways. Such comparative assessments across care studies are rare although there have been some attempts to produce nexus regional comparisons for Latin America, Asia and the Pacific (see ESCAP 2013 and Bellfield 2015). This 'Nexus Outlook' report can be seen as an attempt, although the focus here is on the case study perspective rather than cross-regional synthesis. Alongside the different contributions of regional and cross-regional assessments, Nexus-assessments are often different in regard to the choice of indicators. Indicators that are related to performance or process are more suitable for regional in-depth assessments. Such indicators examine in detail the reality of how water, energy and food issues are governed or managed and the success or failure of interventions. This is often not generalizable nor can it be reproducible to other case studies in other world regions. Instead, in such regional assessments carried out, for example, at a basin or country level, best practices can be identified and suggested for areas with similar contexts. In contrast, cross-regional or comparative nexus assessments are viable via the use of impact indicators. Such indicators, like demand forecasts, use patterns, resource use challenges and resource sharing conflicts, provide valuable insights on sustainability status. They give an outlook on different regions that are often dissimilar. However, through comparison, the range of global or cross-regional challenges facing the common endeavour to secure water, energy and food resources can be identified.

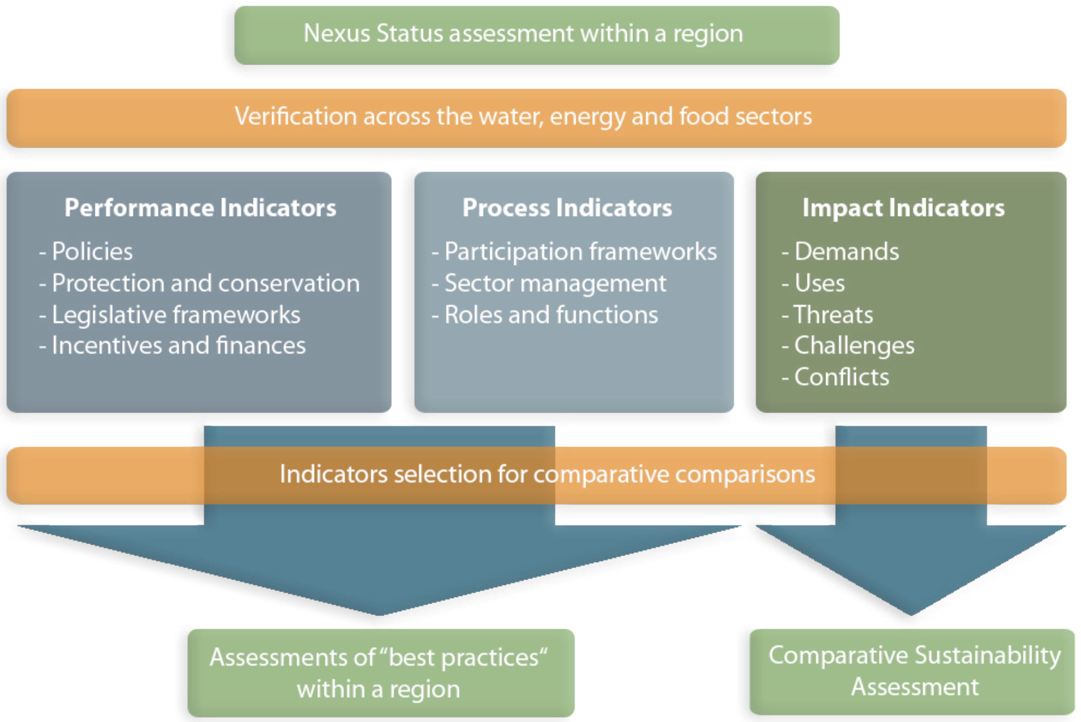
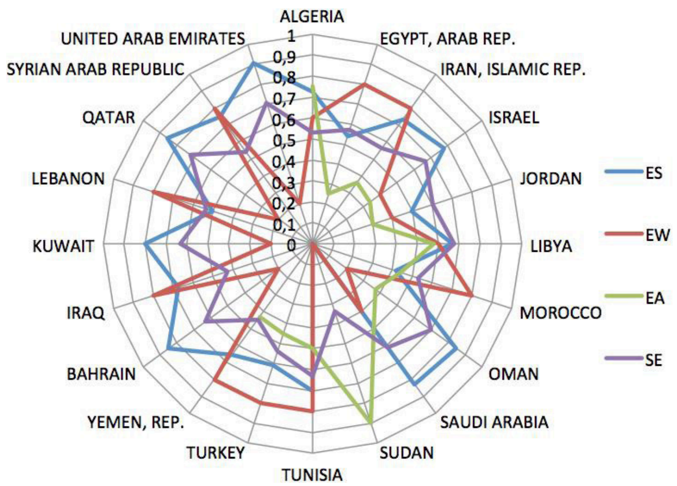


Figure 3: Nexus Sustainability Assessments within and across regions

Selected Assessments for the Nexus

A high degree of experimentation with tools and assessments is one key characteristic of the current nexus debate in academic literature. This phenomenon is quite productive as it helps us develop tools to better understand nexus challenges and interlinks. In this line, the 'nexus outlook' report involved assessment tools with different level of comprehensiveness. Nexus Country Profiles – assessment tools annexed to the printed report version – represent an elaborate set of quantitative and qualitative indicators to evaluate nexus issues on a country-level. They also include a Nexus Rapid Assessment summarizing overall messages. The nexus in-depth case studies in the second chapter provide a better analytical description of a country's nexus challenges with examples from a selected region. The nexus snapshots provided by the short articles in the third chapter provide a highlight of challenges across regions, with a focus on the basin level. The Nexus Timeline included in each case study is an attempt to provide a tool to summarize the evolvement of nexus issues in different regions. There are also numerous examples of nexus assessments in literature (see Al-Saidi and Elagib 2017a for an overview). Some examples can be mentioned here, which had been produced through the Nexus Research Focus of the TH Köln – University of Applied Sciences. Al-Saidi et al. (2016a and 2016b), used global and regional data sets to produce a composite interdisciplinary indices on resource sustainability in the water and energy sectors and applied them to the MENA region. Each index included different cross-sectoral indicators such as water footprints, energy intensity in agriculture or in water production etc. Another descriptive assessment of nexus issues was used to frame the Nile basin transboundary water management issues in Al-Saidi et al. (2017b). Using various indicators based on the profiles of Eastern Nile countries (Egypt, Sudan and Ethiopia), the nexus assessment made the suggestion to promote cooperation using a regional, rather than a basin-focused, cooperation framework. In fact, nexus issues are often not confined to the basin level despite it being the key scale for many crucial nexus interlinks. Through the use of nexus assessment at different levels (e.g. basin, country or transboundary), the broad scope and the complexity of nexus-related interactions become evident and tangible.



Example of nexus assessment using four indicators: energy security (ES); energy for water (EW); energy for agriculture (EA) and socio-economy (SE). Source: Al-Saidi et al. (2016a)

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Nexus In-depth Case Studies

The Water-Energy-Food Nexus: Challenges for the Chilean agriculture

1. Introduction

The world's water, energy and food systems are tightly linked. At the heart of the relationship is the interdependence of resources, how demand for one resource can drive the demand for another. Modern food production demands energy and water at all stages of agricultural production: energy is an important input in fertilizers for irrigation and farm machinery; water extraction requires energy for conveyances and distribution. Climatic changes and environmental pressures combined with population and economic growth will intensify the interactions between resources (GULATI et al. 2013).

This article interrogates the level of interconnectedness between these systems in Chile and discusses how energy and water demand influence agricultural production in the country.

Chile is a long narrow strip of land squeezed between the Andes Mountains and the Pacific Ocean, with a variety of climates and geography. It is one of the leading agricultural producers in Latin America. Unfortunately, with regard to water and energy resources, climate, population and agricultural areas don't line up. The state's largest population centers and agricultural areas are in the semiarid, central part of the country, which requires transmitting energy from the hydropower station from the wetter, southern parts of the state to the north. In addition, Chile has competing interests for the state's water resources: As a major agricultural producer, farmers need water for irrigation, while the continually growing metropolitan area needs drinking water. With so many competing interests, conflicts emerge which call for sustainable solutions.

2. Introduction to Chile´s natural environment in the Nexus-context

The heterogeneous and highly diverse Chilean geography and climate conditions are important for the understanding of the water-energy-food nexus, as their high spatial diversity cause a high number of interconnecting resource questions in the fields of water and energy resources and food production. As indicated in the introduction, Chile is an extremely elongated narrow country (>4200km), reaching from the arid Atacama Desert with an average annual rainfall of less than 1mm in the north to the mildly cold and humid south with precipitations exceeding 5000mm per year. The very limited east-west expansion, with a maximum width of approx. 375km, ranges from the high Andes mountains of up to 7000masl in the east to the Pacific Ocean in the west (ODEPA 2012).

These geographical characteristics lead to a high diversity in environments but, at the same time, to unevenly distributed resource availability such as water and arable land and unequal possibilities for food and energy production. While the humid south registers record passing precipitation and a high potential for hydropower production, the central and northern parts of the country are strongly affected by water scarcity. On the other hand, temperature favors the central and northern parts of Chile where the country centers its most productive agricultural activities and largest parts of the population. Seventy-four percent of the Chilean population is concentrated in the northern-central part on only 11.7% of the Chilean territory (RIBBE and GAESE 2002). Energy and water are therefore of high demand in these areas. Figure 1 shows the main irrigation development zones in central Chile. The figure indicates that the investigation of the availability and distribution of water, food and energy is becoming more and more important as resources are increasingly needed inareas where they are very limited, where these resources are strongly limited.

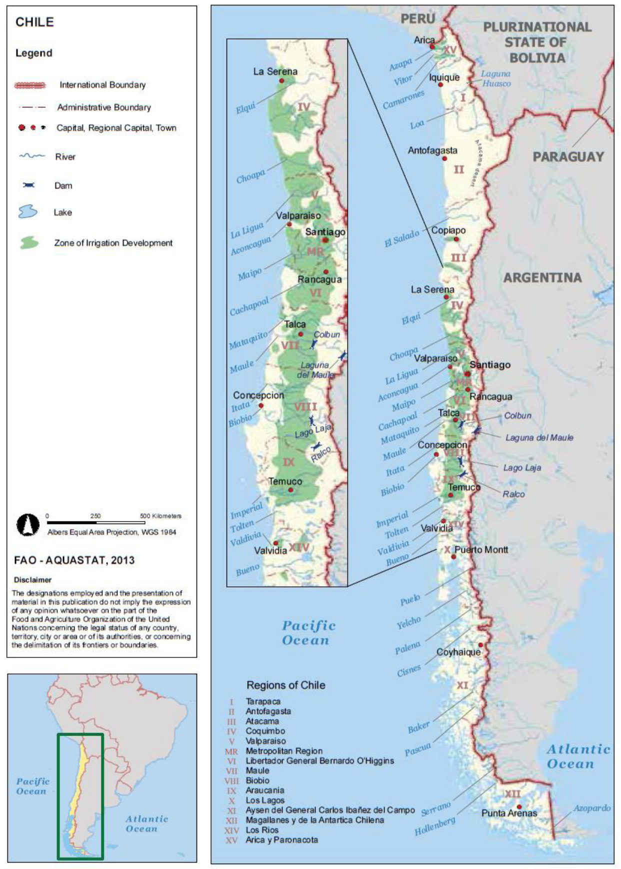

Fig 1: Main irrigation developments zones in central Chile (UN Water 2013)

3. Interactions of Water, Energy and Food

3.1 Food production

Chile is one of the leading agricultural producers in Latin America and an important player in world agro-alimentary markets.

The Chilean agricultural sector includes the following sub-sectors: agriculture, cattle and forestry. The sector has grown rapidly in the past 20 years with the introduction of modern farming methods. This growth has been associated with important structural changes, notably in the agro-processing sector, the logistics of food distribution, and the system of food retailing (the rise of supermarkets) (OECD 2008). Winter demand from the northern hemisphere for fresh agricultural products has led especially to a growth of export agriculture, e.g. from the central valley (ARUMI et al., 2009). In terms of value of production, the country has established itself as one of the top 20 fruit and vegetable producers in the world. Therefore, agriculture is an important driver for Chile's economy. Almost 20% of Chile's population works in the agriculture sector, and it is the most important contributor to Chile's economy after mining (ODEPA 2011). On one hand, the intensive agricultural production allows a steady increase of national harvests and increases security of supply. On the other hand, the agricultural economy, compared with other economic sectors, has one of the greatest impacts on the use of natural resources that may often lead to exploitation and degradation.

Although it is of huge importance for the country, only a small portion of the total 75 mil ha surface area in Chile is suitable for agricultural use. About 5 million hectares is classified as growing soil, 11.2 mil ha as meadow, 0.9 mil ha as forestry and 5.6 mil ha as native forest (MINAGRI 2011). Major agriculture products of Chile include grapes, table grapes, apples, avocados, olives, citrus, cherry, pears, onions, wheat, corn, oats, peaches, garlic, asparagus and beans.

3.2. Water use

Water in Chile is mainly used for agricultural purposes (83.0%), followed by the industrial (13.4%) and the domestic sector (3.6%) (UN Water 2013). With increasing agricultural expansion, especially in water scarce regions, Chile´s water demand grew significantly during the last decades. Water consumption for irrigational purpose increased from approx. 16 mil m3 in 1995 to approx. 20 mil m3 in 2010 (JANSEN et al. 2011). Considering the future climate trend with decreasing precipitation events, increasing temperatures and significant glacier retreat in the semi-arid and arid parts of Chile, the pressure on water resources is in danger of rising considerably.

Excursus: Limarí Basin

Especially in Chile´s most important agricultural regions, like the Limarí Basin, water demand exhibits water availability. The Limarí Basin is one of the most important watersheds in north-central Chile. It covers almost the entire Limarí Province and belongs to the Coquimbo Region (IV. Región, El Norte Chico). Its headwaters lie at the top of the subtropical Andes (>5; 000 masl), and the river flows westward into the Pacific Ocean over a length of approximately 200 km (VICUÑA et al. 2012). The semi-arid climate is characterized by dry and warm summers with mean temperatures of 23.8°C, wet and mild winters (9.4°C) and a mean annual precipitation rate of 125.7 mm (OYARZÚN 2010; Verbist et al. 2010). Eighty-five percent of the annual rainfall is registered between May and June, the winter months (SOUVIGNET et al. 2010), indicating that especially during the hot summer months water is a restricted resource in this area. Furthermore, precipitation events show a high inter-annual variability influenced by the ENSO (El Niño Southern Oscillation) phenomenon, with above average rainfall during El Niño years and below normal rainfall during La Niña conditions (VERBIST ET al. 2010). Dry spells with extremely low precipitation lasting from one to several years are common in the Limarí Basin (FAVIER et al. 2009), and currently the region is suffering from a severe drought, experiencing the 6th year in a row with hardly any rainfall. In spite of the arid conditions that characterize this region, it holds more than 50,000 ha of highly productive agricultural land thanks to its irrigation infrastructure and three interconnected reservoirs.

Fig. 2: Irrigation agriculture (grapes) in the semi-arid Limarí-Basin in north-central Chile (Picture by R. Becker)

In an area that is subject to recurrent droughts, and where precipitation has decreased over the last century, farmers are highly dependent on irrigated agriculture. Nevertheless, in the last decades the cultivated area have increased significantly; currently 48% of the agricultural surface in the whole Coquimbo region is cultivated in the Limarí Valley, and irrigated agriculture is the foremost employment opportunity (SOTO 2000). To cope with this water scarcity problem and to increase the water use efficiency, this area invested in the construction of 3 big interconnected water reservoirs (Cogotí, La Paloma and Recoleta) as well as in the improvement of irrigation methods and channel systems. Nevertheless, increasing water use efficiency is not necessary leading to a reduction of water use. This so called rebound effect (or take-back effect) refers to the systemic responses to the introduction of new technologies that increase the efficiency of resource use. These responses tend to offset the beneficial effects of the new technology or other measures taken. In the case of the Limarí, the higher security of water availability, generated by the establishment of the 3-reservoir system, led to a significant increase in water use due to increasing cultivated land and change in crop patterns. Crops increased instead of the formerly cultivated horticulture and perennial plants, the cultivation of annual, and the agricultural production was focused even more on export oriented crop species. This led to a permanent water demand throughout the year. Today this area is suffering from a severe drought, and in spite of the water reservoir system, the demand for water can´t be fulfilled. Figure 4 (DGA 2013) shows the reservoir level trend of the last years, indicating the extreme water scarcity of the last year. Today (agricultural year 2013/2014) the farmers are forced to abandon vast parts of their productive land to save the little remaining water for their most important cash crops. This development shows the rising interdependency and importance of the water and food nexus.

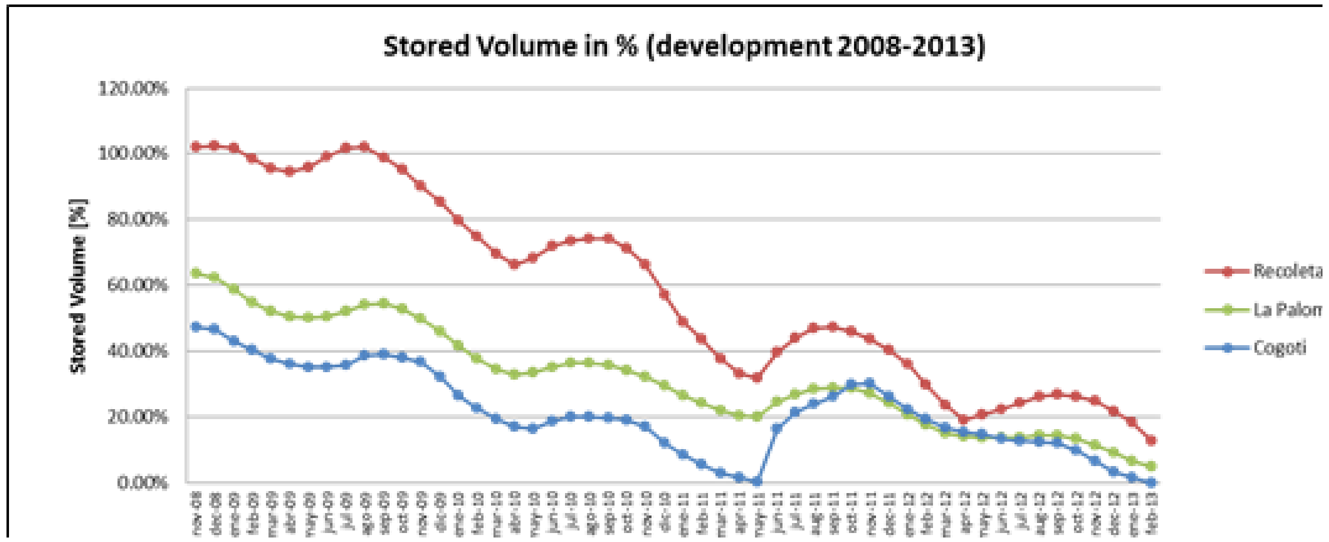

Figure 3: Decreasing water levels of the 3 main water reservoirs in the Limarí Basin (DGA 2013, graphic elaborated by Pablo Alvarez)

3.3. Energy use

Chile is expected to have a very difficult scenario for future development in terms of energy (electricity and fuel) availability. The total installed nominal capacity in April 2010 was 16.050 MW. Most of its energy (70%) is imported, and there is an increasing rate of demand because of the favorable economic situation, the industrialization of the country and technological progress. Additionally, household (non-industrial) energy needs have more than tripled in the last 10 years due to, inter alia, population growth.

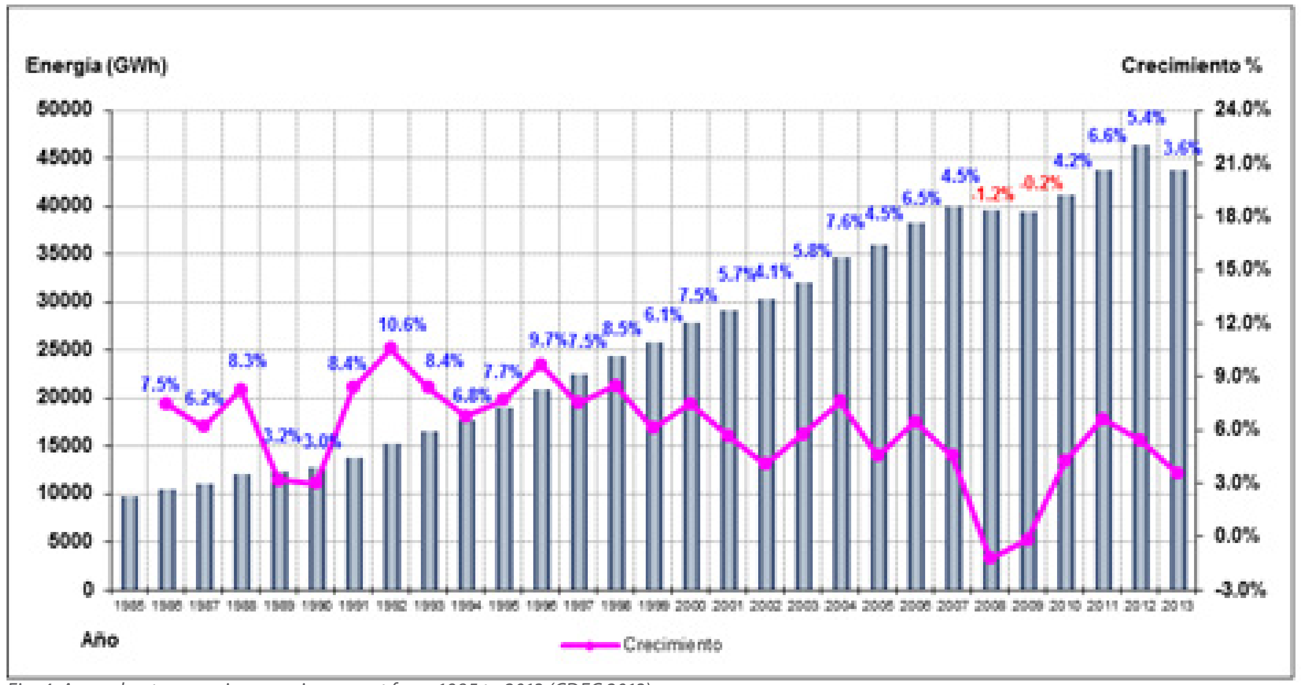

Fig. 4: Annual net energy increase in percent from 1985 to 2013 (CDEC 2013)

Chile has experienced several serious energy supply incidents over the last decade, including major droughts, a sustained gas supply cut from Argentina (since 2004), and a major earthquake in early 2010, which affected electricity networks and refineries and caused several black-outs. The electricity sector in Chile relies mainly on a combination of run-of-the-river and reservoir systems for hydro- power generation (33% of installed capacity), oil (13%), gas (30%) and coal (20%) (CENTRAL ENERGIA 2013). An approximate additional 550 Mwh are currently produced using biomass combustion (2 % of total in Chile) (RUBILAR). Chile produces corn, wheat, and sugar beet, all of which could be used as feedstock for ethanol production. However, given the limited land available in Chile and the current need to import significant quantities of food, second-generation biofuels, particularly from forestry resources, appear to be more promising.

Due to Chile's unique geography, the country's energy markets are regionally disjointed, particularly as the regional gas and electricity grids are not connected. In the arid north, energy demand is dominated by the mining industry and operates based on the separate thermal-based Sistema Interconectado Norte Grande (SING) electricity grid. The more densely-populated central region (including the capital Santiago) operates on the more hydro-dependent Sistema Interconectado Central (SIC) electricity grid. The southernmost, hydro-rich regions of the country are not connected to the rest of Chile in terms of electricity and gas (IEA 2012).

Increased agricultural intensification and mechanization through the use of high-yielding crop varieties, fertilizers and increased irrigation have already lead to an increase in energy use. In the future, this use will likely be constrained by rapidly increasing energy costs. One example is the irrigation district Ovalle, (Limarí, Chile). From 1997 to 2007, a strong change from traditional furrow irrigation towards water-saving micro-irrigation systems, led to an increase of about 65% of irrigated agricultural area (MINAGRI 2011).

In this way, the 'saved water' has led to an extension of the irrigated area, especially in areas at higher altitudes. In the future, pumping energy to locations at high elevation is expected to result in an additional electricity demand of 15% (VICUÑA 2013). The result is an even higher water and energy demand.

Year	Furrow irrigation	Micro irrigation	Irrigated area
1997	70%	29%	14.172 ha
2007	42%	56%	23.378 h

Table 1: Development of irrigation technologies in Ovalle, Limarí (MINAGRI 2011).

4. Challenges

4.1. Climate Change

Agricultural regions located in snowmelt-dominated Mediterranean climate basins like in Chile have been identified as being highly vulnerable to the impacts of climate change. Scientific reports on future climate change impacts show that the contrasting climatic characteristics between the north and the south of Chile will intensify in future. This is true, especially in the in the central-north, where Chile´s most important productive agricultural areas are located and whereprecipitation is estimated to decrease by 10-30% (VICUÑA et al. 2010), leading to reduced stream flow and hence decreasing water availability. Temperatures are likely to increase in these areas by 3-4°C (VICUÑA et al. 2010), reinforcing evapotranspiration processes and aggravating water scarcity (see figures 5 and 6).

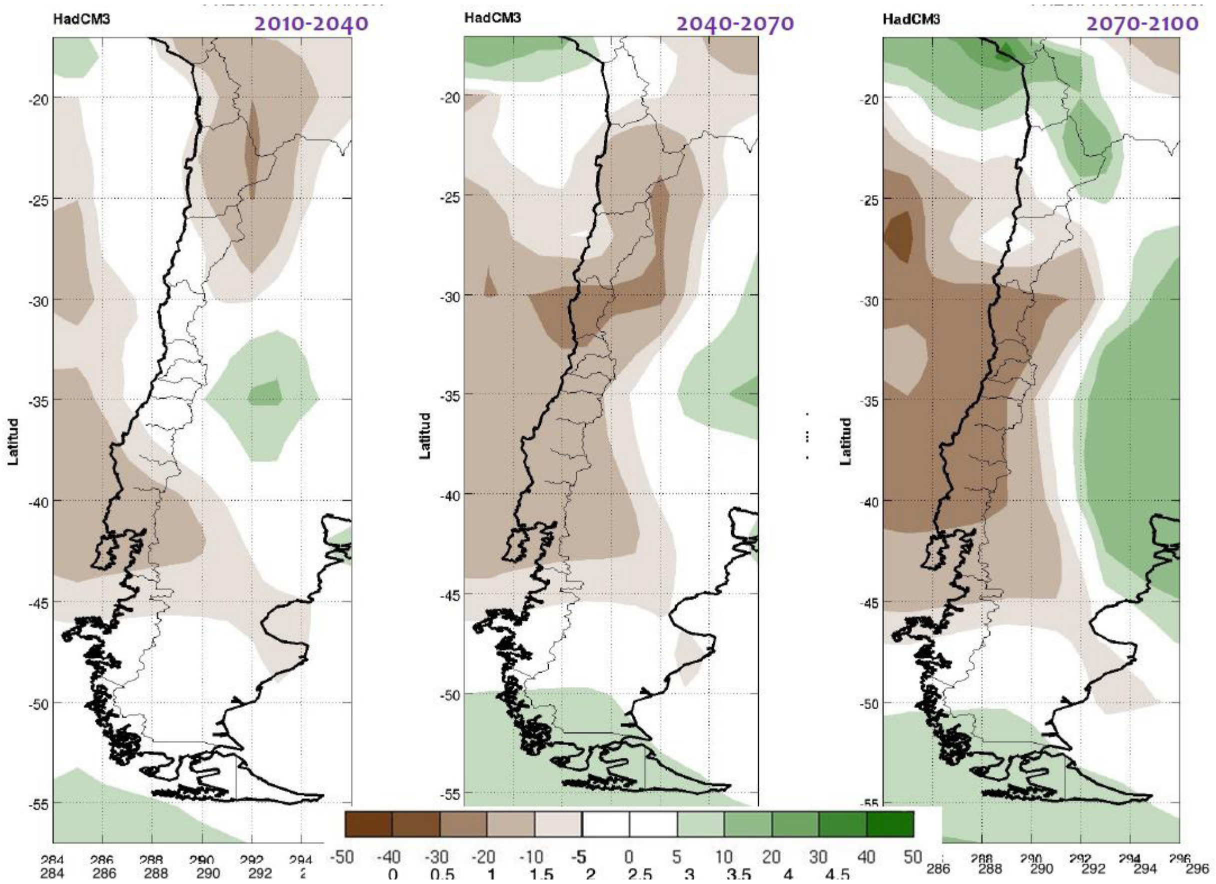

Fig. 5: Rainfall projections HadCM3 (VICUÑA 2013)

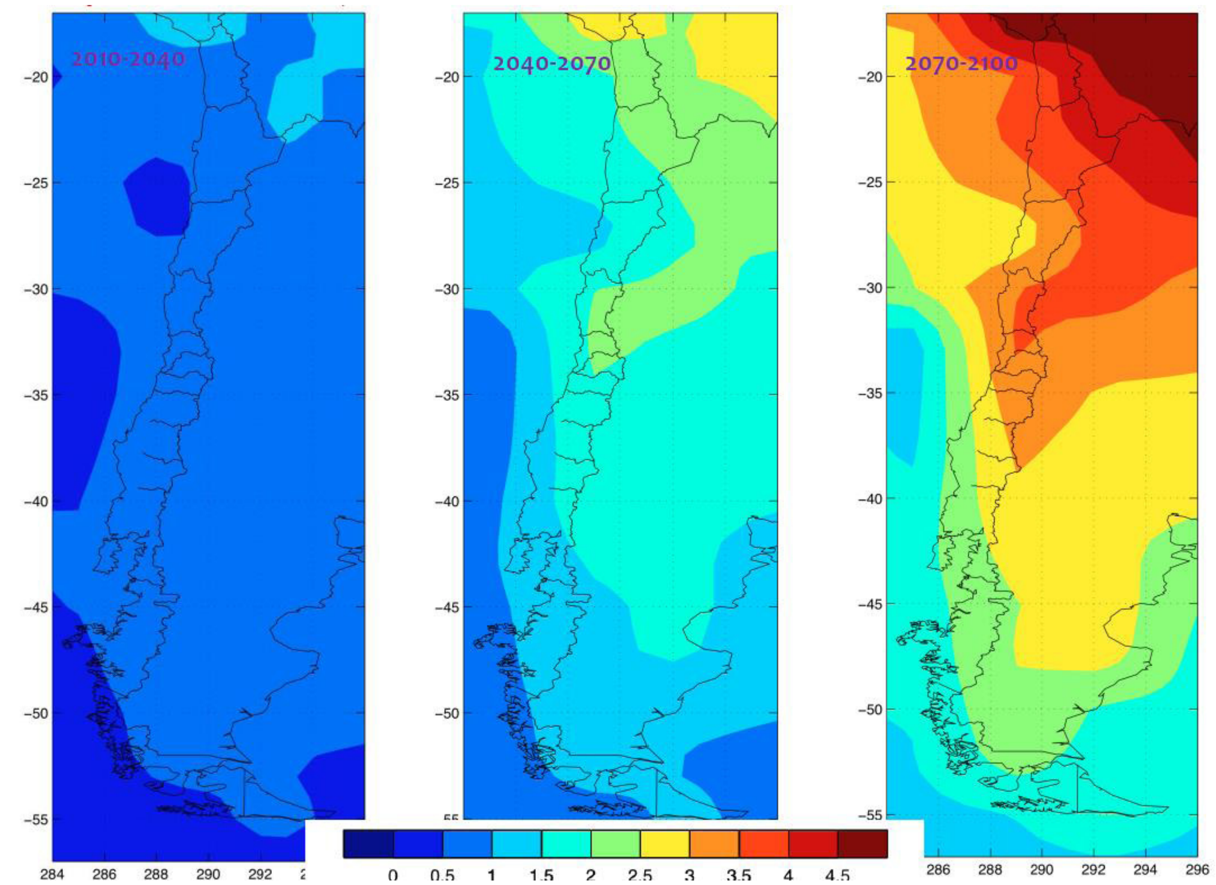

Fig 6: Temperature projections HadCM3 (VICUÑA 2013)

Such changes would affect both river discharge and irrigation water demand. For this reason, the reliability of water allocations may be strongly negatively affected (MEZA 2012).

Higher growing season temperatures and altered precipitation patterns can also significantly impact agricultural productivity and are expected to lead to a shift in suitable growing regions. Increases in the amount of rainfall will likely cause an increase in soil erosion, while occasional lack of rainfall, in times when it usually occurs, may result in drought conditions, causing stress on grapevines. Grapevines, which are widely produced in Chile, are very responsive to their surrounding environment. As it can be seen in figure 7, the suitability and productivity of grapes are projected to decrease in the future, especially in the central, semi-arid part (AGRIMED 2008).

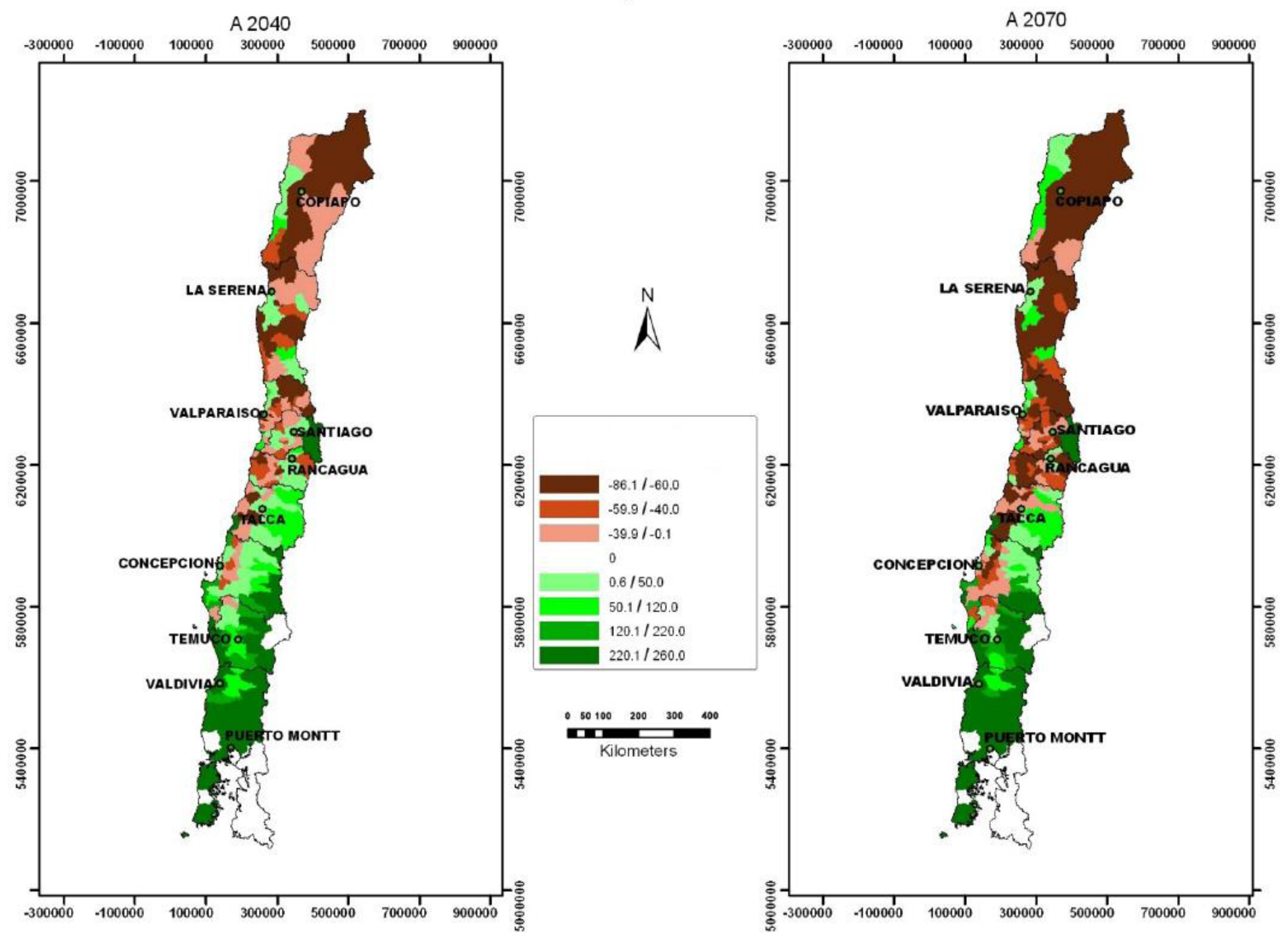

Fig. 7: Productivity change (%) of wine due to climate change (AGRIMED 2008)

Due to higher temperatures in future, the water demand of fruits is expected to increase. One example are apples, an important so called 'cash crop' from Chile. Young and dwarf apple trees are especially sensitive to droughts, and the high crop load also affects their water demand (NEMESKÉRI 2007). Figure 7 shows the future variation for water demand of apples in different Chilean agricultural communities (from the north to the south) under different climate scenarios in the years 2040 and 2070 compared to the present. It can be seen that, especially in the year 2070, the water demand is expected to increase and the large water requirements of the apple trees have to be satisfied by supplementary irrigation.

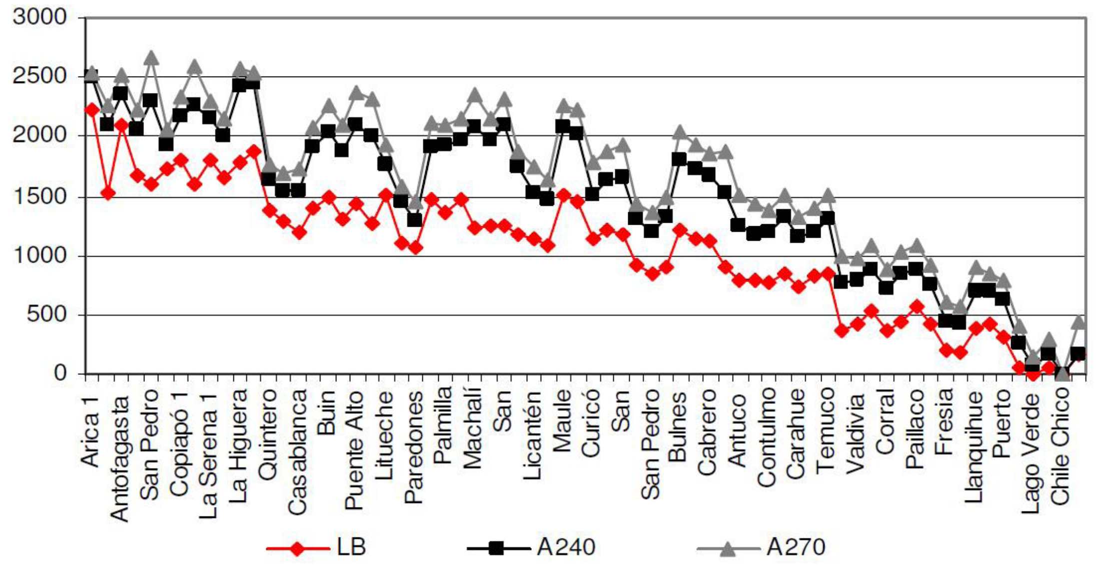

Fig. 8: Water demand of apples under different climate scenarios in different Chilean regions (VICUÑA 2013/CEPAL 2011)

4.2. Economic vulnerability in the agriculture

Vulnerability is often defined as the susceptibility of individuals in a group to a certain event; it is measured as the likelihood that an individual (or a proportion of individuals in a group) will cross a critical threshold. For example, a crop may be vulnerable to failure because of drought or heat stress, or a farm household may be economically vulnerable if its natural resources fall below a critical threshold (ANTLE 2009). The economically most vulnerable region is the central valley (see figure 9), which is highly technologized and profitable in agriculture. One reason for its high vulnerability is that the losses are of greater magnitude due to its strong export-orientation by the cultivation of so called 'cash crops', which are grown for sale to return a profit (e.g. avocados, table grapes, apples etc.). Further, the region is mainly influenced by climatic changes and water and energy shortages.

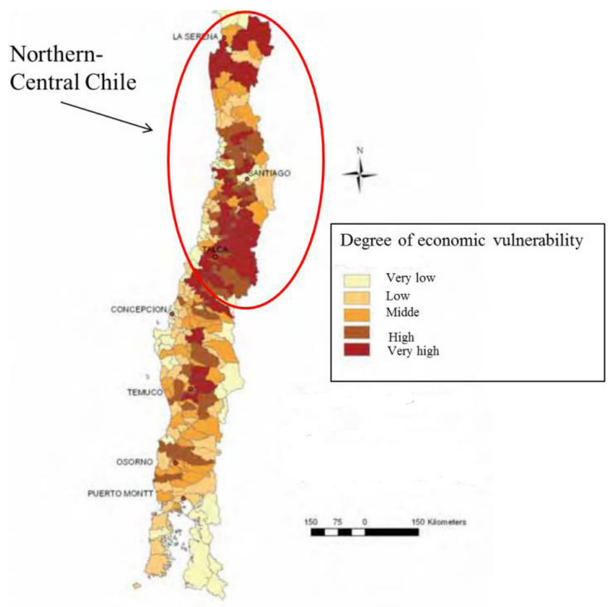

Fig. 9: Economic vulnerability in the Chilean agriculture to climate changes (MINAGRI 2010)

4.3. Vulnerability of hydropower generation

Climatic projections are indicating decreases in precipitation for a large portion of the Chilean territory, and many river systems are showing annual stream flow coefficients of variation greater than 0.5. According to MCPHEE et al. 2010, scientific results indicate that the Chilean electrical grid could face decreases of up to 20% in power input by the end of the 21rst century. As many new hydropower plants in Chile are located in areas sensitive to climate change, hydropower vulnerability to climate change is an issue of great concern in Chile.

One example is the 'Rapel Dam'. The Rapel Dam at the Libertador General Bernardo O'Higgins Region has an installed capacity of 380 MW and generates hydroelectric power. As can been seen in the figure, the level of Rapel Dam shows huge variation between the years 2011 and 2013, with a maximal low in 2013. In 2012, the dam generated just 15 MW (CENTRAL DE ENERGIA 2013).

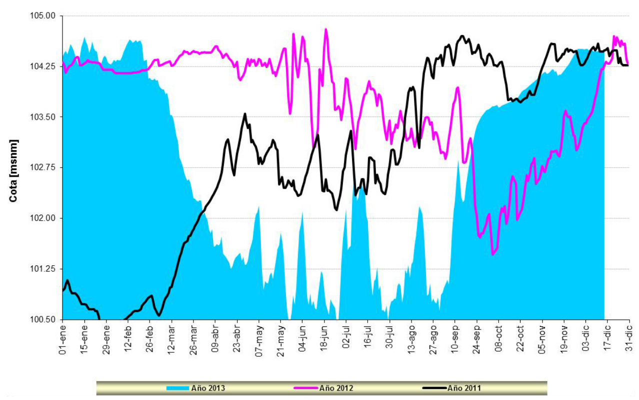

Fig. 10: Level development of Rapel Dam (CDEC-SIC 2013b)

In the year 2014, the country is expected to face its sixth consecutive year of drought, and marginal costs (what companies pay to purchase energy in the spot) market will likely rise. This will have adverse effects on the electricity prices for the end-users and could lead to shortages in supply.

5. Conclusions

The above described developments in Chile indicate that it´s becoming more and more important to combine water, energy and food related issues when discussing sustainable resource management and socio-economic development of the country. Climate change, on the one hand, and increasing economic development and population growth, on the other hand, are leading to an increasing demand for water and energy resources. Chile´s growing economy is accompanied by a significant increase in export-oriented agricultural activities and an increasing focus on high water demanding cash crop plantations. The improvement of irrigation technologies to achieve a better water use efficiency (like described in the Limarí case study) even intensified this development as water resource availability could be ensured with a higher certainty. The resulting increase in agricultural irrigated areas reinforces the dependency on water as well on energy resources to maintain or even expand the high level of agricultural production. Hence, the vulnerability to water and energy shortage is growing with increased resource demand. These processes are leading to an overuse of natural resources, and many parts of the country are subject to ecological degradation such as soil erosion processes or over- fertilization, resources depletion, loss of natural vegetation etc.

The graphic below shows some of these processes which should be jointly addressed in the context of the Water-Energy-Food Nexus in Chile. Even though the graphic can´t be considered as an all-encompassing representation of all interconnected processes, it shows clearly the increasing interdependency of the various dynamics and developments. Once again it illustrates the necessity of a combined approach, incorporating the manifold processes within the Nexus in order to achieve a sustainable resource management.

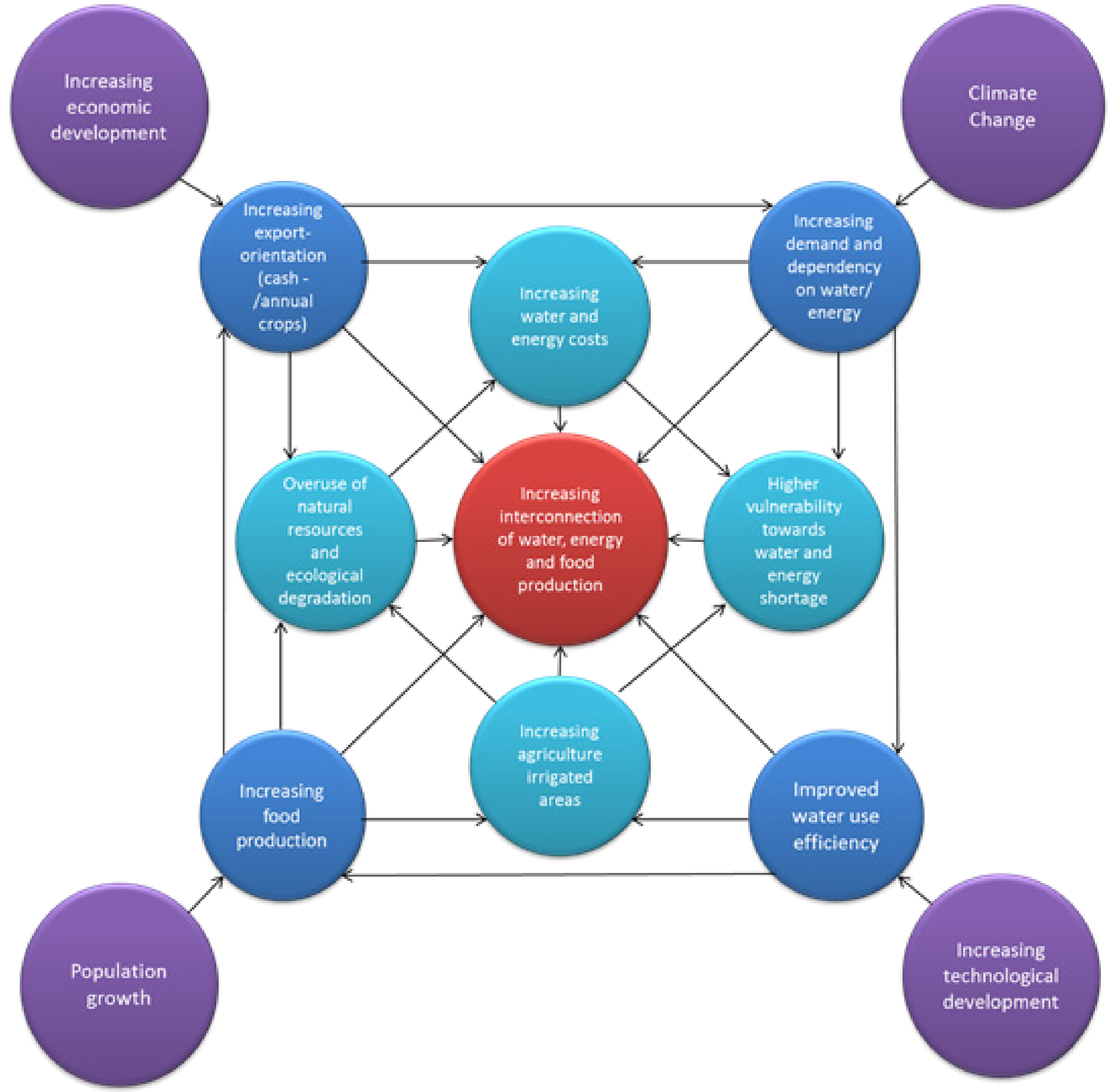

Fig. 11: The interconnection of pressures and drivers within the water-energy-food nexus (own elaboration)

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Hydropower development and its impacts on food production and water supply in Vietnam – An example from the Vu Gia Thu Bon River Basin

1. Surface water resources in Vietnam

Vietnam is located in the tropical monsoon region, with a nationwide annum precipitation of about 1,960 mm. The country owns a dense network of rivers and streams. There are as many as 2,360 rivers over 10 km long, which have a perennial flow, and 15 basins with a catchment exceeding 2,500 km2, of which 10 river basins have a catchment exceeding 10,000 km2 (Thao, 2001). The nationwide average waterway density reaches 0.6km/km2, indicating the richness of surface water resources of Vietnam. The total watershed area for rivers flowing through Vietnam is 1,167,000 km2, of which 837,430 km2 originate from other countries, accounting for 71.7% of the total basin area (MARD, 2008). The total volume of annual surface water resources entering and generated within the countries is estimated at 880×109 m3 (SWECO, 2007).

Major rivers in Vietnam such as Mekong, Red and Ca Rivers have their sources in other countries. Almost every mid and small-sized river is totally contained inside Vietnam's borders. Some tributaries of the Mekong River have their sources in Vietnam, flow through Lao PDR or Cambodia (Se San, and Srepok Rivers) to the Mekong, then return through Vietnam to the sea. The Bang Giang Ky Cung River Basin, located in North Vietnam, is generated in China, flows through Vietnam, and then returns to China.

The mountainous topography, a dense network of rivers and high water availability, is the advantage to developing hydropower in Vietnam. The theoretical potential of hydropower generation in Vietnam is about 300 billion kWh per year, and the technical potential is approved at 123 billion kWh per year. Accordingly, hydropower resources are concentrated in the major river systems of Da (6,800MW); Dong Nai (3,000 MW); Se San (2,000 MW); Lo - Gam (1,600MW); Vu Gia - Thu Bon (1,500 MW); Ma - Chu (760MW); Ca (480MW); Huong (280MW); and Ba (550MW), and small hydropower has a potential of 3,000MW.

Abundant water resources support the development of a diverse agricultural sector. According to national statistics, during the last decades, 75 large irrigation schemes, 1967 irrigation reservoirs, each with a capacity of 0.2 × 106 m3, and a number of other water works were created. These water works are able to irrigate 4.58 × 106 ha¬ and supply 5 - 6 × 109 m3 per year for urban, industrial and services purposes.

In regard to hydropower, Vietnam has the potential for hydropower development. Theoretically, with 2,360 rivers with a length over 10 km, the country Vietnam has potential to produce about 300 billion kWh per year. The Vu Gia Thu Bon (VGTB) is ranked fourth for potential hydropower generation capacity after the Da, Dong Nai and Se San river systems. The total theoretical and economic hydropower potential of the river is estimated at 1,300 MW and 1,000 MW, respectively. Of eight large hydropower plants that are built in the VGTB upstream, seven plants are operating on the principle of returning water to its origin; only the Dak Mi 4 diverts water from Vu Gia to Thu Bon River for higher efficiency. This study shows that the water diversion of the Dak Mi 4 project will cause significant change in the hydrological regime in the lowlands, which in turn causes large problems for ecology and socio-economic development.

2. Hydro-electricity of Vietnam

Due to dynamic economic growth rates, demand for electricity of Vietnam has been growing about 15% per year in the recent years (Bird, Roop, & Nga, 2005). The increasing trend will continue in future with expected growth rate of 14 – 16% in the period 2011 – 2015 before slowing down to 11.15 % per year during the next five years and to about eight percent per year for the period from 2021 to 2030 (MOIT, 2011). In order to ensure the country has plan to provide 194 - 210 billion kWh in 2015; 330 - 362 billion kWh in 2020; and 695 - 834 billion kWh in 2030.

The most important power source has been hydropower, coal and gas thermal power. Nuclear and renewable electricity shares were and are expected to be insignificant during 2010 - 2020 and will become relatively important during 2020-2030. Hydropower shares a large proportion of the electricity amount produced in Vietnam as it accounts for 35% of the total electricity output in 2009, 37% in 2011. This figure will be maintained until 2015 before dropping to around 25% in 2025, according to the national government. According to National Master Plan for power development for the 2011 – 2020 period with an eye towards 2030 (referred to as power master plan VII), the electricity generation of hydropower stations in 2020 will reach 17.400 MW, accounting for 23.2% of the total 75.000 MW of the national electricity production. The share of hydro-electricity in the budget of energy production of Vietnam in 2030 will decrease from 23% in 2020 to 11.8% in 2030, while the participation of coal-fired thermal power will increase to 51.6%. The nuclear power will be developed after 2020 to increase its share from one percent by 2020 to seven percent in 2030 (Figure 1). Although the proportion of hydropower in the electricity generation of Vietnam continuously decreases during period 2020-2030 according to the Power Master Plan VII, the hydropower generation in 2030 compared to 2020 is not changed, and on average, about 64.6 GWh of hydro-electricity is generated in a single year (Vietnam Government, 2011).

According to 2010 data, there are more than 2,100 hydropower reservoirs with a storage capacity of 0.5 million m3 per tank being built in Vietnam, and the total water storage capacity of these reservoirs is estimated at 41 billion m3. Another 240 reservoirs with a total storage capacity of 21 billion m3 will be completed in the coming years (ADB, 2009). These reservoirs will cause significant change in the hydrological regime of the rivers and streams and will directly or indirectly impact the potential use of water resources in downstream.

The largest hydropower stations are mainly constructed along the Da, Dong Nai, and Se San (a tributary of Mekong) rivers (Table 1).

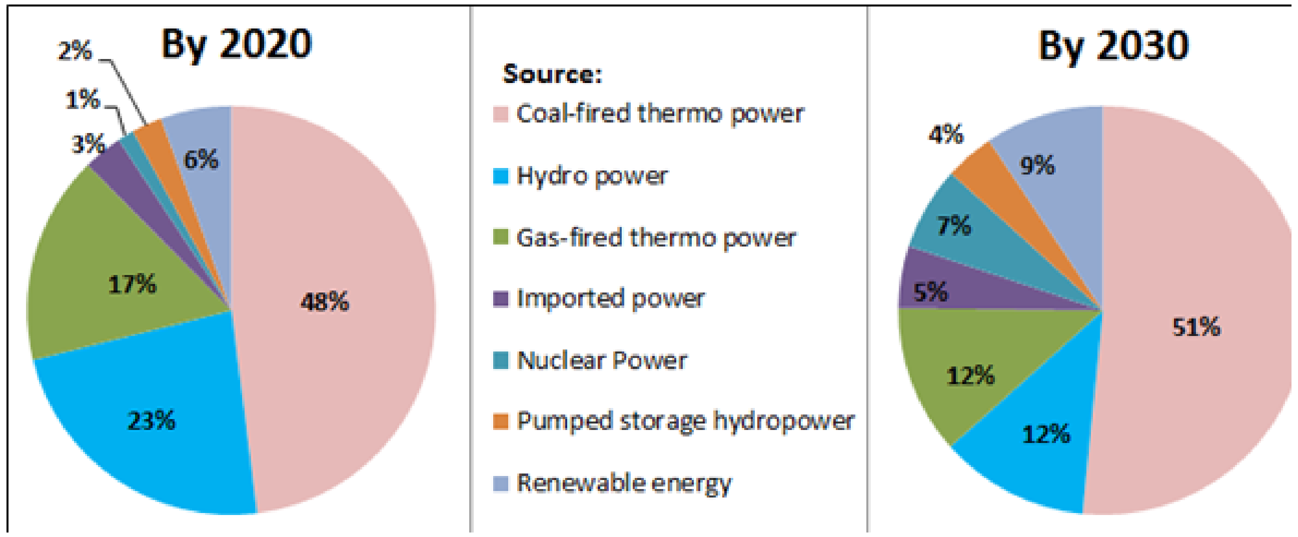

Figure 1. Share in energy source of Vietnam in 2020 and 2030
Source: National Master Plan for power development for the 2011 – 2020 period with the vision to 2030

Rank	Name	Installed capacity (MW)	River
1	Son La	2,400	Da
2	Hoa Binh	1,900	Da
3	Lai Chau	1,200	Da
4	Yali	720	Se San
5	Huoi Quang	520	Da
6	Tri An	400	Dong Nai
7	Tuyen Quang	342	Gam
8	Se San 4	330	Se San
9	Ham Thuan	300	Dong Nai
10	Ban Ve	300	Ca

Table 1. 10 largest hydropower stations in Vietnam
Source: http://www.vncold.vn

The development of hydropower in Vietnam helps to more effectively use water resources and contributes to prevent floods, improve irrigation, reduce the consumption of other fossil fuels as well as create more jobs for local people. Besides its positive impacts, the construction of hydropower dams also brings several negative impacts to the environment and local communities such as changing the hydrological regime of rivers, disintegrating ecosystems as well as changing living conditions and the culture of ethnic groups in the involved regions (Phung et al., 2007)

3. Hydropower development and its impacts to the food production and water supply in the Vu Gia Thu Bon River Basin

3.1 The Vu Gia Thu Bon River Basin

The Vu Gia Thu Bon River Basin (VGTB) is the fifth largest river basin in Vietnam with a catchment area of 10,350 km2, and the catchment is entirely located within the territory of Vietnam.

The profile of the basin has a west-east direction. In the mountainous region, the hill slope varies from 20 to 30 degrees, whereas floodplain and coastal sandy zones are plane. Mountainous areas with elevations from 500 - 2,000m occupy a large part of the basin's area. The Watershed Divide of the basin is mountain ranges with 1,000 - 2,000m high, which cover large areas in the north, west and south direction of the basin. Favorable terrain conditions facilitate trapping the northeast monsoon and high humidity winds from the from East Sea, which provide high humidity for the basin.

Rainfall distributes unevenly in the basin and descends from the mountains to the plains with an annual average value of 3,738 mm in the mountains and 2,181 mm in the plains. The altitude and rugged terrain in combination with a high precipitation provide high potential of hydropower energy for the upper parts of the basin.

The basin has a tropical monsoon climate. The annual average temperature is 24.5oC - 25.5oC in the mountains, 25.5oC - 26.0oC in coastal plains and tends to increase gradually from the north to the south. The lowest temperature falls into January, and the highest temperature is in June. The relative air humidity in the dry season (April to September) is just 77% and can reach to 93% in the wet season (October to March). The river basin is formed by two main sub-basins of the Vu Gia (5,453 km2 at Ai Nghia) and the Thu Bon (3,532 km2 at Giao Thuy). High precipitation makes the specific discharge rate of Thu Bon (Nong Son) reach 0.089 m3/s/km2. The mean annual discharge of Thu Bon (Nong Son) is approximately 281 m3/s. High seasonal variability of stream flow is the typical characteristics of the hydrological regime of the basin. During the wet seasons, the average discharge is as high as 525 m3/s, but it decreases sharply to below 100 m3/s in dry seasons. Up to the Thanh My, the sub-catchment of the Vu Gia has an annual mean discharge of 127 m3/s, and the specific discharge is 0.069 m3/s/km2 in comparison to 0.089 m3/s/km2 of the Thu Bon.

The lowland of the basin concentrates large economic centers, of which Danang is the fourth largest city in Vietnam. Beside that a large part of the lowland area is used for rice production. Therefore any change in the hydrological regime upstream due to hydropower development can positively or negatively impacted on the economic activities and livelihoods of the local people in lower parts.

3.2 Hydropower development

The hydropower potential of the VGTB ranks 4th in Vietnam, just after the Da, Dong Nam and Se San rivers. High rainfall and steep terrain are the ideal conditions to install hydropower stations in the basin. Up to date (end of 2013), there are 44 hydroelectric projects, with the installed capacity from 0.6 MW to 215 MW, being constructed or confirmed to be constructed in the basin.

Not until the beginning of 21st century was the first large hydropower plant installed in the basin. Afterward, the region saw a dramatic increase in the development of hydropower. The VGTB with its high precipitation and relatively high relief is ideally suited for electricity production. The total theoretical and economic hydropower potential of the river is estimated at some 1,300 MW and 1,000 MW, respectively, and the annual energy potential at about 6 TWh and 4.6 TWh, respectively. Hydropower developers took advantage of these conditions and built hydropower stations in many sites. In 2007, the A Vuong was the first large scale hydropower facility to commercially produce electricity in the region. Since this beginning, the hydroelectricity industry has been experiencing tremendous growth and change.

Figure 2. Sites of hydropower stations in the Vu Gia Thu Bon River Basin

Hydropower facilities range in size from small stations to large dams. Small facilities often depend entirely on stream flow as their storage capacity is small. Currently, 44 hydroelectric projects are confirmed to be constructed in the basin. Plants range in generating capacity from 0.6 MW to 215 MW. There are 8 major projects, which belong to Vu Gia Thu Bon Hydropower Cascade (Table 2).

The construction of hydropower in the upstream region is the most notable intervention of human beings into the natural environment to cause the change of hydrological regime downstream. The most potential hydropower sites are located in the upstream of the Vu Gia subbasin, and due to the basin's low topographic relief, the potential hydropower of Thu Bon subbasin is smaller. The Upper Vu Gia subbasin has been undergoing extensive hydropower development in its upper reaches of the Bung and the A Vuong. Up to 2013, there are 6 large-scale hydropower plants of the A Vuong, Song Tranh 2, Song Con 2, Song Bung 2, Song Bung 6, and Dak Mi 4 were completed another 2 large plants of the Song Bung 4 and Dak Mi 1 are expected to be completed in next two years.

Project	Catchment (km2)	Mean annual flow (m3/sec)	Installed capacity (MW)	Annual energy (MWh)
A Vuong	682.0	39.8	210	815.0
Song Tranh 2	1,100.0	106.0	162	620.7
Song Bung 2	324.0	18.9	100	415.0
Song Bung 4	1,477.0	88.2	156	618.0
Song Bung 5	2,388.0	139.0	85	371.0
Dak Mi 1	396.8	26.4	215	824.0
Dak Mi 4	1,154.0	68.9	180	743.0
Song Con 2	248.0	13.2	46	168.0

Table 2. Large hydropower projects of the Vu Gia Thu Bon Hydropower Cascade
Source: Quangnam Department of Natural Resources and Environment, 2007

Out of eight hydropower plants are built in the VGTB upstream, has seven plants operating on the principle of returning water to the origin water, only Dak Mi 4 diverts water from Vu Gia to Thu Bon River for higher efficiency (Fig.2).

The Dak Mi 4 Hydropower is located on the Dak Mi River and makes a water diversion from the Dak Mi River at the elevation of main dam of 240 m a.b.s.l to the upper Thu Bon River at the elevation at the power housing station of 60m a.b.s.l. The project has an upper reservoir with an area of 10.4 km2 that will provide an active storage of 158×106 m3, corresponding to about 7% of the mean annual inflow of 68.9 m3/s (SWECO, 2010).

Although other large hydropower projects are able to avoid water shortages in the dry season by reserving water within the reservoirs and providing compensatory flows during dry periods. However, in order to provide adequate water for multi-purposes in dry seasons, it requires the long term cooperation among the hydropower operators.

Although hydroelectric production neither consumes nor removes water, it has great impacts on hydrological conditions downstream. Due to limited storage capacity, all most hydropower facilities in the region prefer to operate in peak hours. Releases from hydropower plants are greatly increased during brief periods of high energy demand and greatly decreased most of the time during low energy demand. Periodic changes in turbine discharges results in highly variable flows downstream. This may cause adverse impacts on water use and salt intrusion downstream. Despite these problems, reservoirs can play an important role in maintaining minimum flows during drought periods.

Construction of hydropower reservoirs upstream with regulating and/or diverting will affect the hydrological regime downstream both the daily and seasonally pattern. Out of eight hydropower plants built in the VGTB upstream, seven plants operating on the principle of returning water to its origin, only theDak Mi 4 diverts water from the Vu Gia to the Thu Bon River for higher efficiency. The change of catchment area of the sub-catchment Vu Gia and Thu Bon before and after the construction of the Dak Mi 4 project is illustrated in (Figure 3).

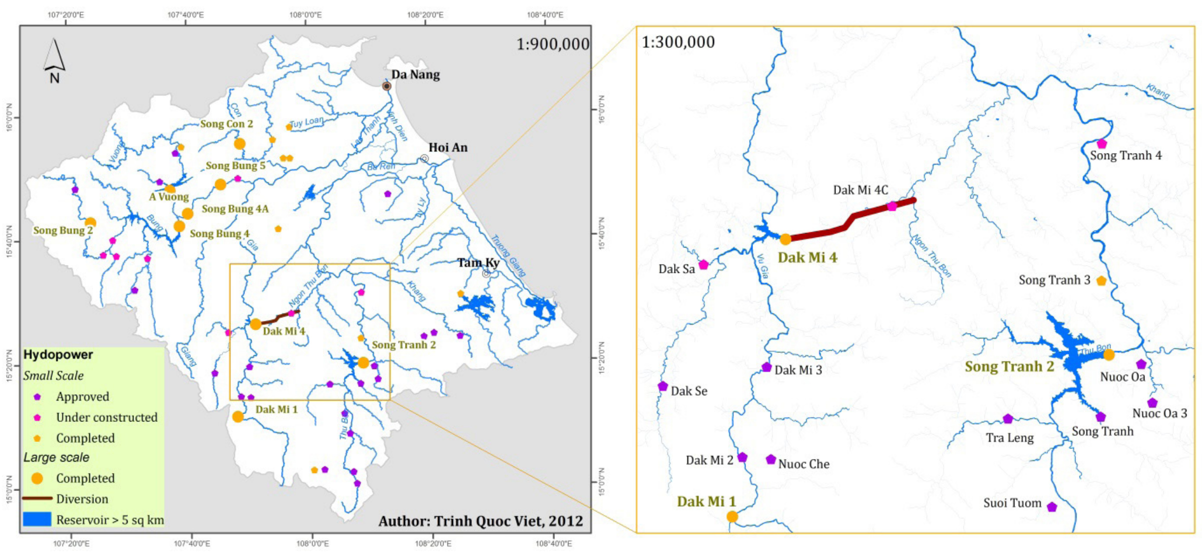

Figure 3. Water diversion from Vu Gia to Thu Bon through Dak Mi 4 Dam

Before constructing of the Dak Mi 4 hydropower reservoir, Vu Gia has the catchment of 6,123 km2 up to the mouth but after diverting water to Thu Bon, its catchment area is reduced 1,256 km2, account for 20% of whole catchment. On the other side, the catchment area of Thu Bon is increased about 30%. With the proposed operational procedure, all the water from the reservoir will release to Thu Bon. This leads to the fact that downstream of Thu Bon will get more water and downstream of Vu Gia will get less water (Figure 4). Lower flow in dry seasons implies that more salt will intrude in to the Vu Gia.

Figure 4. The flow of Dak Mi after Dak Mi 4 Dam is disappeared

3.3 Food production and impacts of water diversion of Dak Mi 4 on food production

Although industry and services play a more important role in the economic activities of the region, the agricultural sector still share 20% and 3% GDP of Quangnam Province and Danang City in 2013. Moreover, about 50% of the region's labour force is working in the first section.

Plantations are the main agricultural activity in the region as it accounts for a larger proportion than livestock cultivation. Perennial trees are cultivated in the area of 1,409 hectares in Tien Phuoc, Tra My, Tay Giang, Dong Giang, Nam Giang. Among them are cinnamon, tees, pepper, and cashew. In 2010, about 117,925 ha in the basin were used to cultivate paddy rice; annual crops and perennial crops (MONRE 2010) account for 11.4 % of the catchment area. Rice is cultivated in low-lying areas, where water resources are ample. Alluvial is the dominant soil type in the estuary. Rice is mainly cultivated in the the coastal plains (Figure 6). Most of the paddy farms in the lowlands and midlands along the major rivers are irrigated, while the paddy farms in the uplands are mainly fed by rain. However, the water for irrigation in the lowlands is affected by salt intrusion in the dry season.

Before 2000, rice was planted in three cropping seasons, in which the third season lasts from August to October. When growing in this period, rice usually suffers from floods and storms, and therefore, the yield was substantially low. Since 2001, only two cropping seasons have been applyied in the region. The winter-spring crop takes place from December to April, and the summer-autumn crop takes place from May to September. Rice yield in the winter-spring crop is often higher than that of summer-autumn due to the favorable weather conditions and secured water availability. Two crops per year permit the prevention of damage from floods and storms, but droughts and salinity intrusion are still challenges.

Subsidiary crops such as sweet potato, cassava, bean, peanut, tobacco, and vegetable are planted in higher areas. Annual crops are planted on 36,878 ha (2010) mainly concentrated in the lowland and midland. Compare to paddy rice, these plants need less applied water. Until 2010, all irrigation schemes in the region were designed to supply water paddy fields rather than other crops.

Weather condition conditions play a large role in agricultural production as it can influence crop growth, yields, incidence of pests and diseases. In order to prevent damage from extreme weather events, the crop calendar is set up locally for each year based on weather and climatic forecasts. This leads to the fact that there are some small differences between sowing days from year to year, but in general, winter-spring crop follows the the offset of the seasonal rains at the end of December and is harvested before auxiliary floods, which may occur in May. The second crop, namely summer-autumn, will start in later May and will be harvested before early floods, which may occur in the beginning of October. Meanwhile, the growing calendar of rice is rather fixed; the planting days of annual crops are much variable and depend on resources available.

In order to supply water for irrigation, there are a large number of water works constructed in the region. The agricultural landuse in the region is irrigated either by reservoirs, by weirs or by pumping stations. Counted in 2007, there are 73 irrigation reservoirs constructed in Quangnam Province to irrigate 22,239 ha. There are also 521 small weirs constructed to irrigate 5,222 ha. While the small weirs and reservoirs are constructed mainly in the midlands and uplands, the pumping stations are constructed in the lowlands to irrigate 8,100 ha (IMC, 2010). Of three sources of irrigation, irrigation through pumping stations is most affected by hydrological change caused by hydropower development upstream.

There has been a decrease in agricultural landuse in recent years due to urbanisation and industrialisation. According to socio-economic planning of Quangnam Province and Danang City, large parts of agricultural areas will be converted to other purposes. Landuse change occurs frequently in the coastal zone due to tourism development (Figure 6). Although the cultivated areas have decreased, the rice production of the region is increasing about 2% pear year from 334,083 tonnes in 1996 to 417,900 tonnes in 2011 (QSO, 2012).

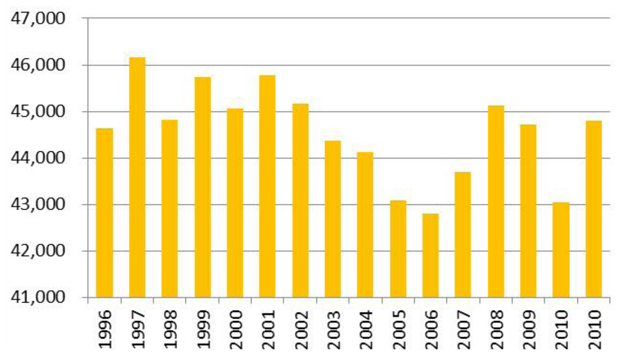

Figure 5. Planted area of paddy rice in 197-2010 period

The water diversion of the Dak Mi 4 project will cause significant change in the hydrological regime in the lowlands. According to the calculation of DARD Danang, the average discharge demand of the downstream Vu Gia is 84 m3/sec, and to maintain base flow, a 111 m3/sec is required (DARD 2007). The basic flow of 111m3/sec is crucial to supply enough water for pushing back salinity, maintaining environmental flow, supplying water for irrigation and other purposes. However, as the Dak Mi 4 plant is built up, the downstream discharge will be reduced some 47 m3/sec (Fig.1), which will cause huge ecologic and socio-economic problems, in which a clean water supply is one of the most serious problems. The negative impacts of water diversion of the Dak Mi 4 project is mentioned by ICEM, (2008): "The diversion involved in the current design of the Dak Mi 4 project will create unnecessary and far reaching negative environmental, social and economic impacts in the Basin. The favoured mitigation is to redesign the project without the diversion. This will reduce the power capacity but eliminate the most serious negative risks. If the development has proceeded too far to consider this scale of redesign, then, as a second option, a water supply gate should be incorporated into the current project, so that its operation will avoid a major problem for water supply for Da Nang Province." The study's impact assessment of hydropower construction on food production, therefore, only focuses on water diversion of the Dak Mi 4 project.

Based on the calculation of local authorities of Danang City, the water conversion of the Dak Mi 4 Hydropower will cause insufficient water supply for 850,000 inhabitants during seven months of the dry season (February to August) every year. Twenty thousand hectares of irrigated paddy rice of the An Trach Irrigation System on the Vu Gia River will be adversely affected. Before the Dak Mi 4 was built, ICEM, (2008) warned that water diversion of the Dak Mi 4 Project can cause harmful impacts in terms of environment, society and economics in the region. However, the project is continuously run with disagreement between local authorities and project owners.

Figure 6. Food production areas located downstream of hydropower dams

In terms of human interventions, reservoir construction, water diversion, weir operation and increasing water extraction are regarded as the main factors causing patterns of salinity intrusion. As mentioned previously, there are several reservoirs constructed upstream, in which the Dak Mi 4 diverts water from the Vu Gia to the Thu Bon. This leads to change of low flow in both rivers of Vu Gia and Thu Bon. Downstream of the Vu Gia will receive less water, while the downstream flow of the Thu Bon will stronger. In 2012, a salt front of 1.0 g/L appeared further on the Vu Gia and the Vinh Dien but shorter on the Thu Bon due to the water diversion of the Dak Mi 4.

Salt intrusion has a wide range of impacts on growth and productivity of crops. It may cause soil salinisation, disruption of normal growth of plants or difficulties in supplying adequate water for irrigation. In the context of the VGTB, salt intrusion would not directly affect crops but it could cause water shortage or drought for cropping in the region. The river water is not suitable for irrigation as its salt concentration exceeds 1g/L.

3.4 Impacts of water diversion of Dak Mi 4 on drinking water supply for Danang City

The Vu Gia and the Thu Bon are the main sources to supply water for domestic use and other purposes of Danang city. The daily domestic water demand of Danang in dry season 2013 stands at 205.000 m3, of which 80% was withdrawn from the Vu Gia River (Table 3). In another word, the Vu Gia is the dominant sources to supply water for Danang City, and under the water diversion of the Dak Mi 4 project, the water security for the city is dramatically affected.

Plant	Capacity	Source
Cau Do	145,000	Vu Gia
Cau Do (extended)	25,000	Vu Gia
San Bay	30,000	Vu Gia
Son Tra	3,000-5,000	Lake
Hai Van	1,000-2,000	Cu De

Table 3. Domestic water demand of Danang in dry season 2013
Source: DAWACO, 2013

According to the Da Nang City authorities, converting water of the Dak Mi 4 Hydropower plant will cause an insufficient water supply for 850,000 inhabitants in seven months of the dry season (from February to August) every year.

Due to the water diversion from the Vu Gia to the Thu Bon, the downstream of the Vu Gia is frequently suffers from water shortage not only for irrigation but also for domestic and other uses. In order to supply adequate water for Danang City, since 2005, the Cau Do Water Supply Plant has had to convey water from upstream An Trach Weir instead obtaining water directly at the site of the plant. In 2012, the plant has to pump water from the An Trach in 1,721 hours. Operating the An Trach Pumping Station will add more operational cost. For each cubic meter of water pumped from An Trach, a 459.2 VND is added to the operational cost of the plant. Diminished flow of the Vu Gia after the water diversion adds more salt to the river. Exceeding salt (> 0.25 g/L) at Cau Do prohibits as-usual operation of the Cau Do Water Treatment Plant, which is in charge to supplying 80% of the drinking water for Danang City.

4. Conclusion

The Vu Gia Thu Bon has a rich hydropower potential. This is the ideal condition to develop hydropower projects at different scales to meet the increasing electricity demand of Vietnam. To date, there are 44 hydropower projects being constructed or confirmed to be built in the basin to generate approximately 5,000 × 106 kWh per year. Hydro-electricity generation, on one hand, brings high economic values for hydropower developers but, on the other hand, causes significant impacts on agricultural production and drinking water supply downstream. The water diversion of the Dak Mi 4 project is recognised as the factor causing severe drought in the downstream of the Vu Gia, which in turn directly affects the water supply for 850,000 inhabitants of Danang city and the irrigation of 20,000 ha of paddy rice in the region.

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Nexus Snapshots

Blue Nile Falls, by Ben Robbins

The Blue Nile - Growth and Conflict along Transboundary Waters

With around 84% of the inflow to the main Nile, the Blue Nile is resource-rich and highly important for transboundary cooperation along the Nile, the world's longest river which the Greek named "Nelios" (river valley). The Blue Nile originates from the outlet of Lake Tana in the Ethiopian highlands. It reaches the borders of Sudan with a fall of 1300 meters and later joins the White Nile in Khartoum, the capital city of Sudan. The White Nile rises in the Great Lakes region of central Africa and runs through South Sudan where it loses half of its waters in the Sudd swamp region. From the confluence of the two river in Khartoum, the Nile River is formed and continues its course through Sudan and Egypt. In the Nile Delta in the north of Egypt, the Nile spreads out into different distributaries and finally drains into the Mediterranean Sea. The Nile is the lifeline for Egypt as is it constitutes around 97% of its water resources. Sudan also depends on the Nile for irrigation and electricity generation. Ethiopia is increasing its utilitzation of Nile waters in the Blue Nile in realization of the great untapped potential for energy and agricultural production. Still, water development along the Blue Nile embodies many common challenges for riparian countries due to natural variability, climate related impacts and resource use conflicts.

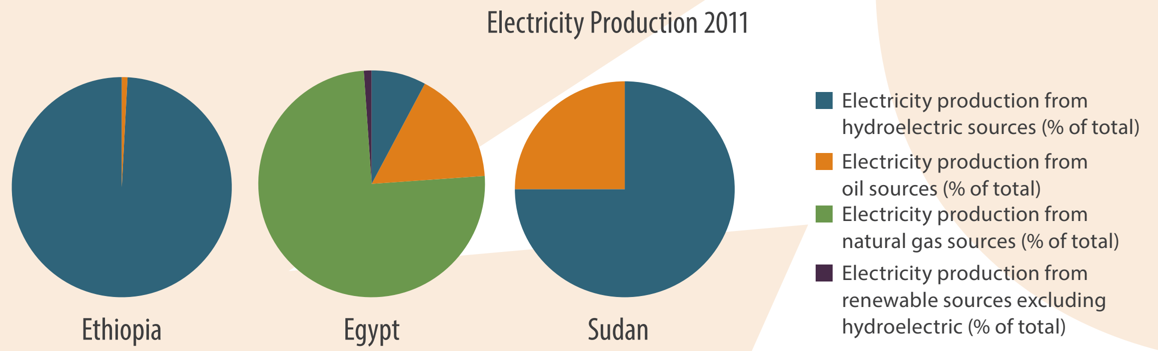
Increasing use of water, energy and food resources

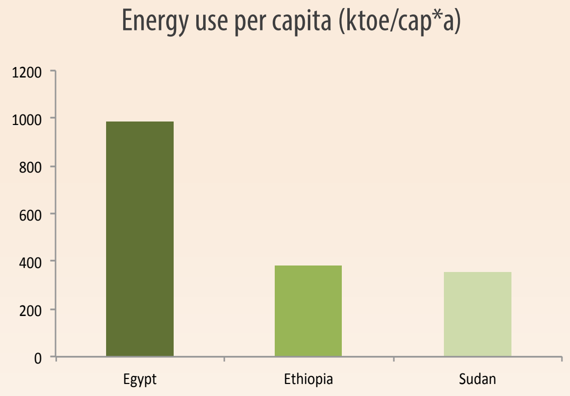
Population and economic growth in Ethiopia, Sudan and Egypt led to increasing pressures on the shared water resources. The population of the three countries increased from around 28 million in 1990 to more than 236 million currently, economic growth in Sudan and Ethiopia accelerated in recent decades but still lags behind Egypt which has a per capita income of 3365 US dollar per year - in comparison to 574 in Ethiopia and 1875 in Sudan (World Bank data from 2011-2015). Egypt acheived much of its growth in the 20th century. As a British protectorate, Egypt received assitance in constructing modern irrigation networks along the Nile River. After its independence in 1953, Egypt expanded its infrastructure by enlarging the Aswan Dam, which effectively controls the flow of the Nile into Egypt, providing irrigation water and mitigating annual variability. Similarly, Sudan profited from the British who built the Gezira irrigation scheme in 1925 between the Blue and While Nile south to Khartoum. The scheme is considered the largest irrigation scheme under single management with around 1 million hectares of cultivated land. In constrast, the utilization of the Nile river for agriculture is rather low. In recent years, Ethiopia began to invest in irrigation and exploit the great hydropower potential along its part of the Blue Nile. In order to face the increasing demand for energy, Ethiopia commissioned the construction of the Grand Ethiopian Renaissance Dam, (GERD) expected to finish in 2017. With a capacity of 6000 MW, the GERD will be the biggest hydropower plant in Africa, three times the capacity of the Aswan dam in Egypt. Since then, the GERD has been the source of much tension among the three countries due to the unknown impact on downstream countries.

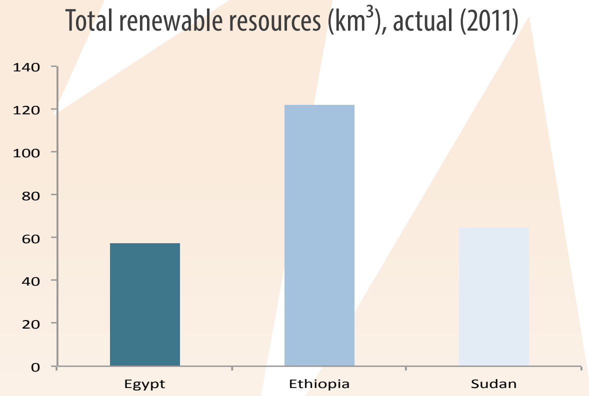
"Water development along the Blue Nile basin embodies many common challenges for riparian countries worldwide due to natural variability, climate related impacts and resource use conflicts"

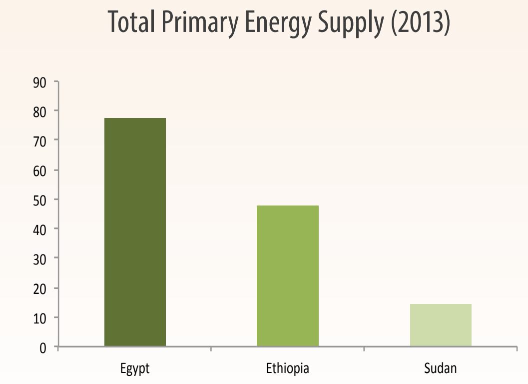
-Mohammad Al-Saidi & Emma Roach

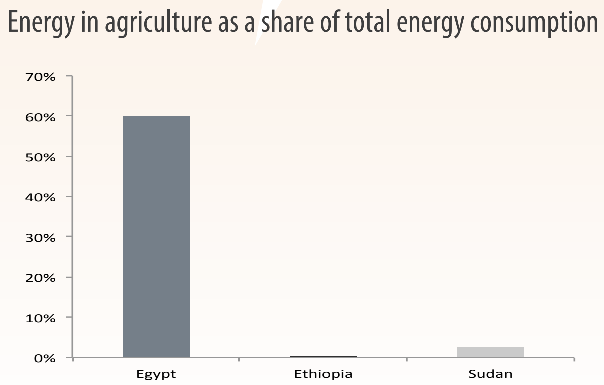
Along with coordinating the water utilization and development projects, Ethiopia, Sudan and Egypt face common challenges in regard to water, food and energy securities. Water use efficiency for agriculture is quite low due to over-irrigation and technological underdevelopment (Deininger et al. 2011 & Al Zayed et al. 2015). Further, the three countries face different pollution-related challenges due to the lack of systematic assessment and monitoring of industrial activities (Al-Saidi et al. 2016). Another challenge, especially in Ethiopia and Sudan, is illegal logging because fossil fuels are not economically accessable for poor households. In Ethiopia, around 200,000 hectares of forest cover are lost annualy, causing land degradation and the loss of biodiversity. (Reegle 2012). In the period 1990-2006, Sudan lost 11,6% of its total forest due to deforestation related to fuelwood production (Butler 2010). Finally, access to electricity is quite low in Sudan and Ethiopia. Such a situation has motivated the two countries to construct hydropower plants like the above-mentioned GERD or the Merowe dam constructed in Sudan in 2009 with a capacity of 1250 MW. In contrast, Egypt has achieved universal access to electricity. Still, energy consumption for water in Egypt is generally high because water supply depends on pumping water from the Nile for irrigation of cultivated land, using more than 560 pumping stations and 1600 pumping units (Feytan et al. 2007).









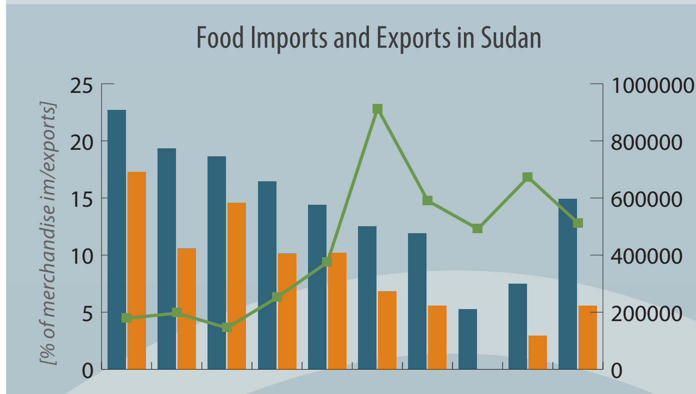


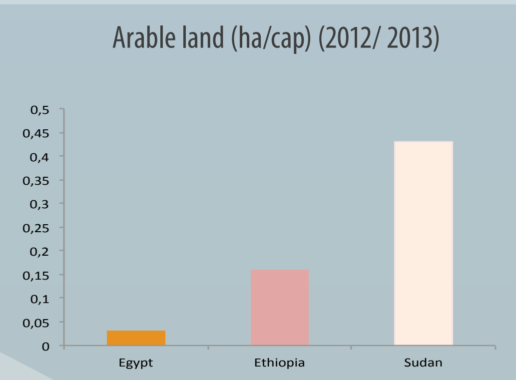
Energy use and hydropower development along the Eastern Nile

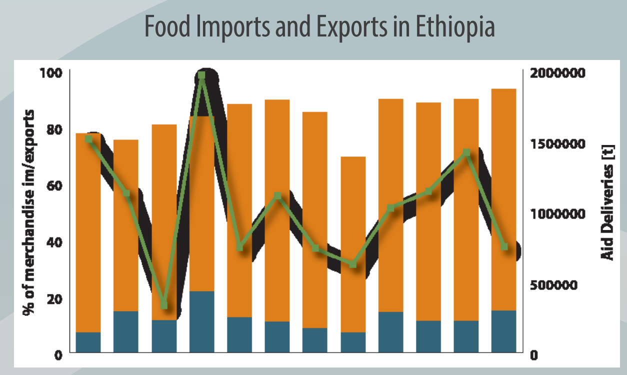
Hydropower is an increasing source of energy production in the basin. The great hydropower potential in Ethiopia and Sudan has motivated the two countries to build new dams like the Grand Ethiopian Renaissance Dam (GERD). These dams are also used for river flow control and for irrigation, especially many small-scale multi purpose dams. Still, energy production through hydropower will not satisfy the increasing demands in the long-run. In fact, Sudan and Ethiopia shared a very low rate of access to electricity of around 30% in 2015 in both countries (World Bank Database). In contrast, Egypt has almost a universal access to energy with agriculture as a heavy energy user. The energy potential in the three countries varies depending on the production source. Ethiopia has a great potential for hydropower which is not entirely dependent on the Nile basin. Egypt has a siginificant potential for fossil fuel. In contrast, Sudan has been dependent on energy production from South Sudan since before the independence of the latter. Biofuel can emerge as an important energy source for Sudan. Currently, fuelwood is being heavily used in a decentralized and unregulated manner in both Ethiopia and Sudan as a source of energy. This causes problems of land degradation and increases siltation in the Nile River.

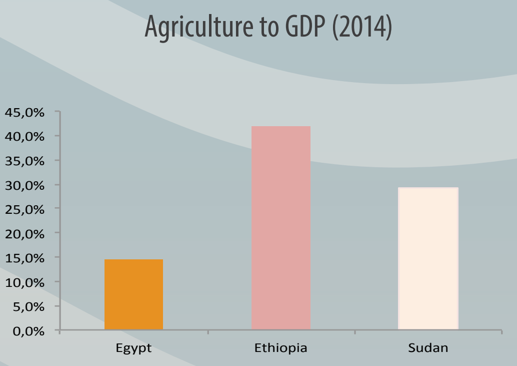
Land use and food security in Ethiopia, Sudan and Egypt

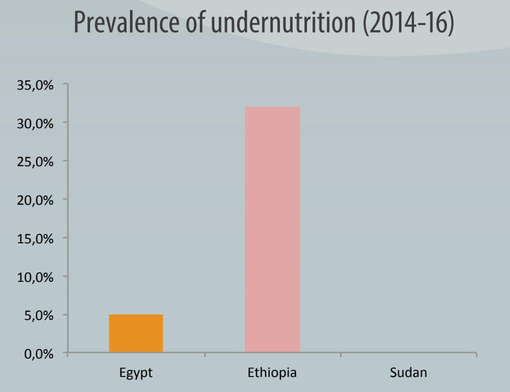
Ethiopia, Sudan and Egypt depend on agriculture for the livelihood of the majority of poor households and for a relatively large share of economic production and employment. The arable land potential is highest in Sudan. At the same time, Ethiopia possesses a significant agricultural production potential which is largely unused. The level of technology use (mechanization) in Ethiopia is very low and agriculture is largely rain-fed based. In contrast, Egypt's arable land is almost entirely under use and dependent on irrigation from the main Nile. Despite the strong agricultural potential in the eastern Nile basin, undernutrition is a serious problem due to the lack of technology, climate variability, adequate markets and low water use efficiency in agriculture. To face this important food security challenge, machinery use in agriculture is expanding, especially in farming systems with large-scale, commercial purposes. Except for Egypt, the majorty of agricultural enterprises in the region are small-scale farms using etiher hand power or draught animals. With increasing mechanization, energy use is increasing. In large farming schemes like the Gezira irrigation scheme (1 million hectare) in Sudan, mismanagement and lack of maintenance are also problems leading to low agricultural performance.

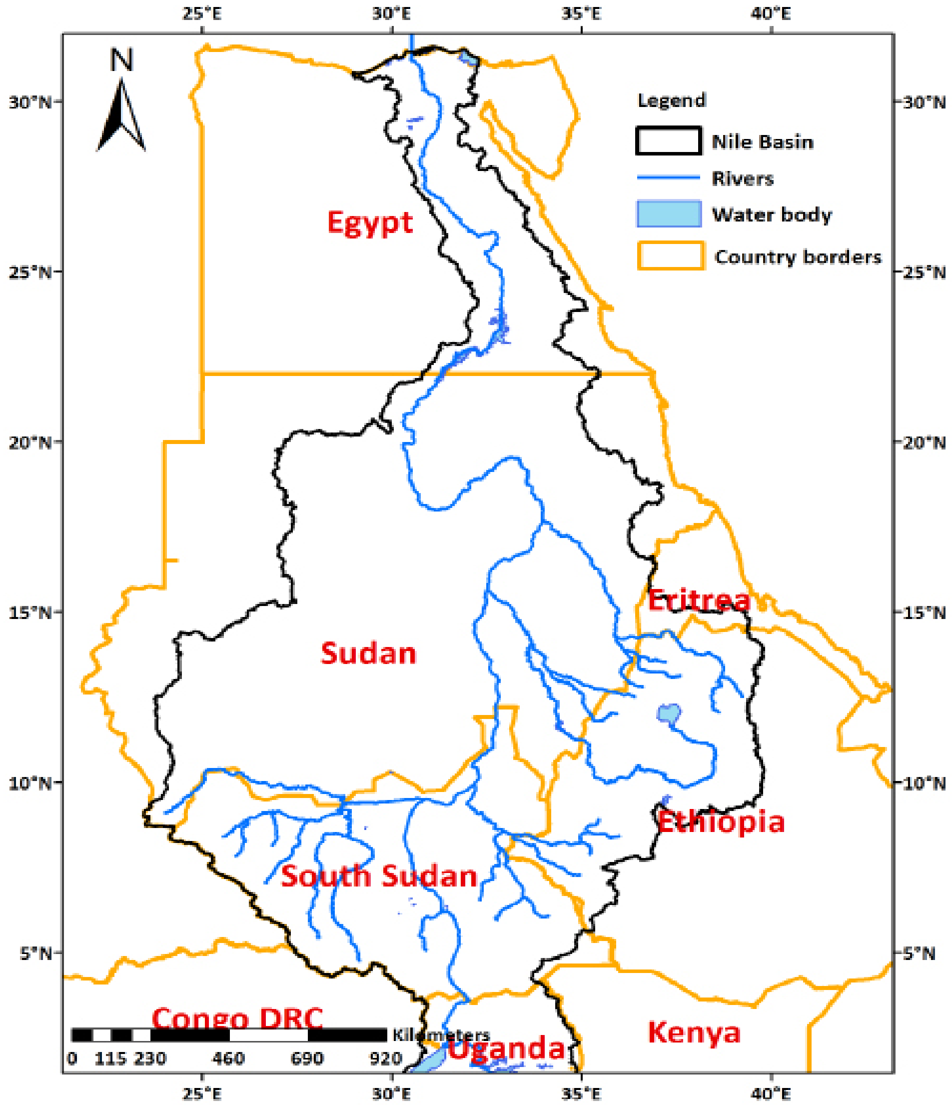












Renegotiating use rights and cooperation framework

Under the British rule, Egypt was given exclusive rights to use Nile waters, prohibiting any development projects in the upstream without the approval of Egypt. After the post-colonial era, upstream countries started to demand more equitable use rights. In 1959, Sudan agreed with Egypt to divide the entire annual river flow estimated at 84 billion cubic meters among the two countries - 18.5 for Sudan and 55.5 for Egypt. This agreement was rejected by the other riparians. In 1990, the Nile Basin Initiative (NBI) was established as a forum for cooperation among the Nile countries. Alongside joint investment in the projects exemplifying win-win cooperation potential in using Nile waters, the NBI sought to outline a new transboundary treaty. The 2010 Nile Basin Cooperative Framework Agreement was rejected by Sudan and Egypt, while the other NBI countries agreed to ratifiy it. Egypt is still holding onto its historic rights and is highlighting the fact that it is almost entirely dependent on the Nile for its water supply. Other countries have alternative water supply resources. Nonetheless, the utilization of the high internal agricultural and hydropwer potential in these countries seems a palatable option to meet urgent growth pressures. This common upstream-downstream tensions over water sharing is increasingly threatening security in the region.


Lake Tana, Ethiopia, by Mohammad Al-Saidi


Farmer in Ethiopia, by Mohammad Al-Siadi


Ethiopian Highlands, by Mohammad Al-Saidi

Regional integration beyond Nile waters

In the face of common resource security challenges, cooperation between Ethiopia, Sudan and Egypt is a viable option which goes beyond Nile River. Regional cooperation can be achieved in mainly three areas: international trade, financial cooperation and technical cooperation. Regional trade is based on exploiting the comparative advantage of each country. There are different resource potentials in the three countries. Ethiopia has the potential to become the region's prime energy exporter owing to the big hydropower potential beyond the Nile waters. Furthermore, cultivated land potential can be used for producing biofuels as an interesting trade option alongside the trade of food products. In this regard, Sudan seems to have a clear competitive advantage with around 105 million hectares, compared to 13.2 million in Ethiopia and 4.4 in Sudan (FAO databank). At the same time, Egypt has a long-standing history of irrigation optimization and technology use and thus is a resource for trade. The other regional cooperation potentials related to technical and financial cooperation are also significant. The higher level of technological specialization and economic power of Egypt allows it to benefit from investments in Sudan and Ethiopia. Supported by a stronger private equity market, Egypt has made some land investments in Sudan for food production, while its capital involvment in Ethiopia's agriculture is limited. Egypt can import vital virtual water through trade with Sudan and Ethiopia, for example in livestock imports. Finally, technical cooperation through the exchange of techncial knowledge and expertise is a win-win option. Cooperation on data sharing and the development of reliable observation networks can help build trust and outline the areas of cooperative resource utilitzation.

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Nexus Timeline: The Blue Nile Basin

The Nile basin has experienced turbulant times of discovery, increasing development, disputes and transboundary conflicts. The Blue Nile basin has been at the heart of the transboundary water sharing dispute caused by increasing internal demands and the aspiration of riparian countries to free themselves from past colonial rule. The current conflict centers around the framework for equitable and just utilization of the Nile rivers. Colonial agreements favored downstream countries (Sudan and Ethiopia) which largely still depend on Nile waters for basic securities. Increasing river engineering in upstream countries (e.g. Ethiopia) demands close collaboration between riparian countries to maintain peace and foster common development. Regime-based cooperation via river basin organizations like the Nile Basin Initiative raised expectations of harmonic cooperation from sharing the same Nile waters.

Events · Projects · Statistics · Agreements

1858
British explorer Hanning Speke discovered the Great Lake region as the source of the Nile

1900
Population of Blue Nile Countries:

Egypt	10 Million
Ethiopia	12 Million
Sudan	6 Million

1902
Construction of the **AsWan Low Dam** for irrigation and floodwater storage in Egypt by the British

1925
Construction of the large-scale **GEZIRA IRRIGATION SCHEME** at the confluence of the Blue and White Nile south of Khartoum by the British

1929
AGREEMENT BETWEEN EGYPT AND THE BRITISH on behalf of other riparian countries to give Egypt exclusive use and monitoring rights over the Nile waters

1959
AGREEMENT BETWEEN SUDAN AND EGYPT on the distribution of the annual Nile flow among the two: Egypt: 55.5 BCM, Sudan 18.5 BCM, Evaporation: 10 BCM

1970
Construction of the **HIGH ASWAN DAM** for flood control, irrigation and hydroelecticity in Egypt by the post-revolutionary government

1975
Population of Blue Nile Countries:

Egypt	39 Million
Ethiopia	27 Million
Sudan	16 Million

1980S
Widespread starvation in Ethiopia and Sudan due to drought

1999
Establishment of the **NILE BASIN INITIATIVE** as a regional cooperation partnership among Nile riparian countries

2009
Construction of the **MEROWE DAM** on the main Nile in Sudan, supplying the country a large proportion of its electricity

2010
Nile **Cooperative Framework Agreement** signed among riparian countries to seek more equitable utilization, with a strong opposition from Egypt and Sudan

2015
Egypt, Sudan and Ethiopia agree to cooperate on resolving disputes over the use of Blue Nile waters

2016
Completion of the construction of a 6,000 MW hydropower plant (**Grand Renaissance Dam**) on the Blue Nile in Ethiopia, near the boarders of Sudan

Population of Blue Nile Countries:

Egypt	93 Million
Ethiopia	102 Million
Sudan	41 Million

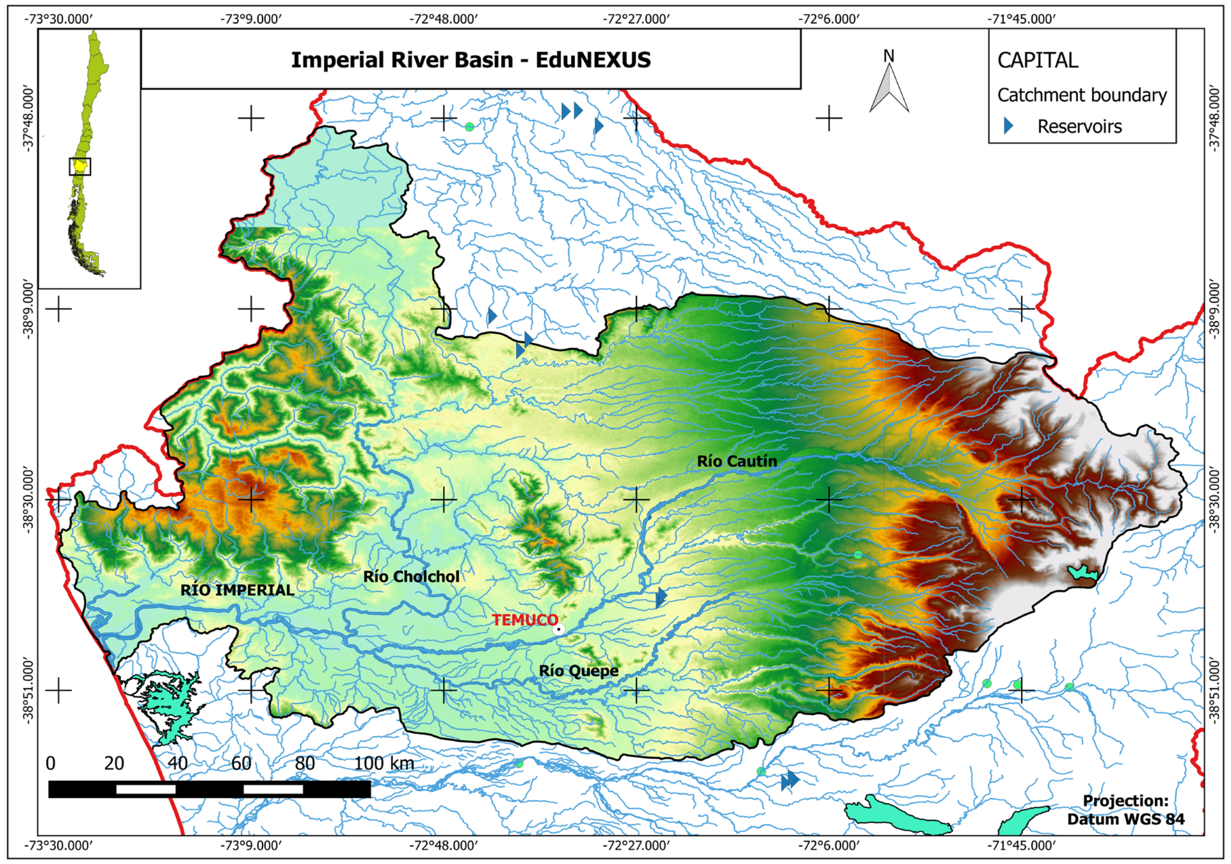

Figure 1: Location of the Imperial River Basin, in southern Chile (South America).

Dimensions	Indicators	Antofagasta	Araucanía	Chile	OECD average
Income	Household income per capita, 2010 (USD PPP per capita)	5 801	3 898	6 275	18 775
Labour	Unemployment rate, 2012 (%)	4.8	7.6	6.6	8.1
Education	Share of work force with tertiary education, 2010 (%)	40.8	23.4	31.2	28.4
Health	Life expectancy, 2010 (years)	75.7	76.7	79.0	79.8
Environment	CO_2 per capita, 2008 (tonnes per person)	25.8	2.8	4.3	10.7
Innovation	No. of patents per million people, 2010	3.5	1.0	6.0	108.8

Source: OECD Regional database. Household disposable income per capita data are based on USD constant PPP, constant prices (year 2005).
Note: OECD regions refer to the first administrative tier of sub-national government; Chile is composed by 15 Regions.

Table 1: Basic features of the Araucanía region, in comparison to Chile and OECD countries.

Imperial River Basin – Challenges in a growing multi-cultural region

The Imperial River Basin is located between 37°51 and 38°56 latitude south, and its drainage area covers about 12 005 km2 in southern Chile (see Figure 1). The main water course is the Imperial River, which is formed by the confluence of the Cautín and Cholchol rivers, with an average annual flow of 260 m^3/s and 230 km from its head in the Andes mountain range to its mouth at the Pacific Ocean. Administratively it belongs to the Araucanía region, which is rich in natural resources, forestry, livestock, farm and has had a recent boom in international tourism due to its natural beauties (volcanoes, ancient forests, ski resorts, lakes, rivers, fishing, spas, mountains, etc). Despite its potential wealth, it is the poorest region of Chile (see Table 1 and Figure 2), with high rates of poverty and socio-economic inequality (HDI=0.686).

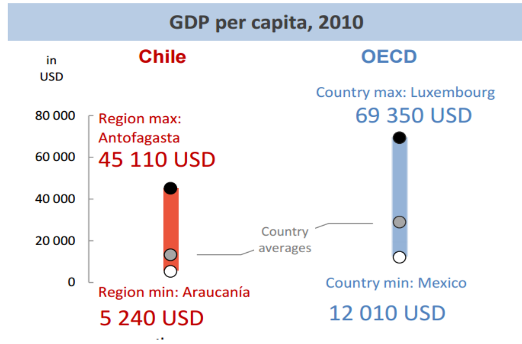

Figure 2: GDP per capita in the Araucania region, Chile and OECD countries. Source: OECD regional database.

Until recently, Araucanía was dependent on cereal farming, and was known as "Chile's granary". The main economic activity in the region is agriculture, mainly crops such as oats, barley, rye, lupine and potatoes. These crops, except potatoes, represent the largest cultivated areas of the country. Recently, the region has undergone a process of diversification, with an increased production of hazelnuts and berries, mostly in the surroundings of Gorbea. Livestock production is also remarkable, especially in the cattle category, which makes it the second largest productive region in Chile, with more than 700 000 cattle annually.

In recent years, forestry has experienced considerable growth, mostly Pine and Eucalyptus in the province of Malleco. The availability of water in the Araucanía region is equivalent to 49 273 m3/person/year, and the relative ratio of availability to demand of water resources seems favourable. However, despite the relative average abundance in the region, the reality in some rural areas is far from favourable. The situation has become extremely severe, considering that a large percentage of the rural population concentrated in the Araucanía use drinking water from streams and wells (without purification), which currently are dry most of the year. The answer to this shortage has fallen in the municipalities and regional governments, which have had to implement emergency systems for distributing water to rural sectors, volumes that barely cover the basic needs of human consumption, causing strong social, cultural, and economic impacts in the affected areas.

Agriculture and forestry development

The main land uses within the basin correspond to native forest, agriculture, grassland, shrubland, and forest plantations. The total irrigated area in the region is around 70 000 ha, while the potential area for irrigation is 135 300 ha (Quiroga, 1987). Currently, 90-95% of the agricultural lands belongs to small farmers, and 80% of the agricultural demand is not satisfied. In this context, the main objective of the regional authorities of the agricultural sector (SEREMI) is to transform rain-fed areas into irrigated ones, and to provide enough water to supply the increasing demand. In addition, recent effects of climate change (i.e., increase of temperature and decrease of precipitation) has made possible the emergence of vineyards and other crops that a couple of decades ago were unthinkable in this region.

On the other hand, there are 483 482 ha of exotic forest plantations in the region (monocultures), mainly Pinus radiata (53%) and species of Eucalyptus (44%, INFOR 2015).

Since 2008, the species with the largest area of plantation has been Eucalyptis, to the detriment of the Pinus surface, reaching a total plantation rate of 19 thousand hectares per year (INFOR 2014). It should be noted that scientific studies mention that Eucalyptus has the highest rate of water consumption of all forest species (Scott and Prinsloo 2008, Huber et al. 2010).

Between 1993 and 2007, a decrease of 116 830 hectares of agricultural land, 63 467 hectares of meadows and shrublands, and 39 827 of native forest was registered. In the same period, an increase of 220 854 hectares in the area occupied by forest plantations took place. Land use changes are consistent with the results of the Census of Agriculture and Forestry (INE 2007), indicating a conversion of agricultural land to forest plantations, affecting arable land and food security in the region.

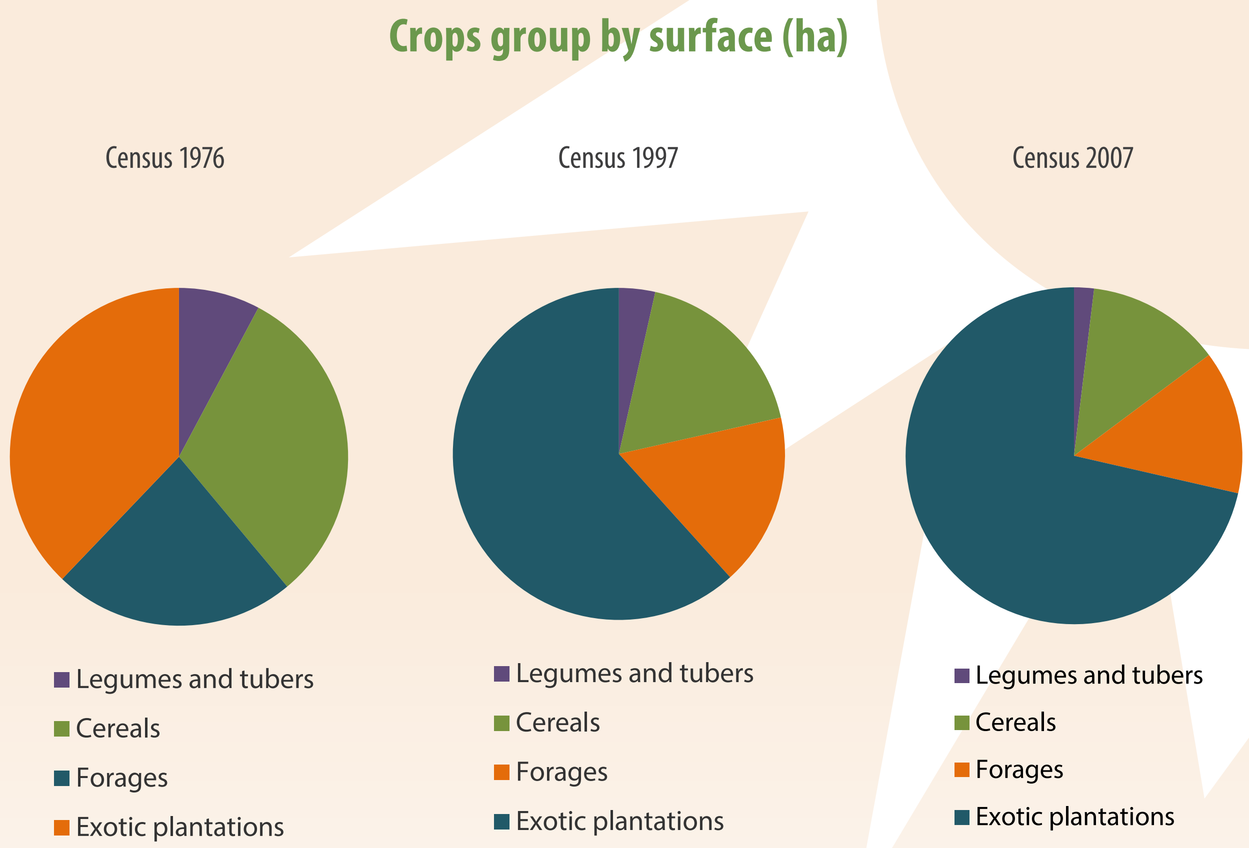

Figure 3: Evolution of main Land covers in the Araucanía region, between 1976 and 2007.

Mapuche protest

Following the independence of Chile, the government opted for peaceful relations with the Mapuche communities and did not begin effective territorial occupation until 1862. Currently, conflicts in the region between Mapuche and forestry and agricultural companies are constantly present because of historical events, where many Mapuche lands were expropriated and then sold to private companies. Today there are many programs in the region administrated by the National Indigenous Development Corporation (CONADI) to address land conflicts and encourage Mapuche communities to improve their economic conditions. Despite the enormous resources for buying land, machinery and equipment, the programs have not resulted in an improvement in the living conditions of the beneficiaries, but in substantial damage to the regional economy. For the Mapuche, water (ngenko) is not only a vital element for human, animal, and plants consumption, but a producer and giver of resources and energy services. Therefore, several Mapuche communities make an active opposition to the construction of hydropower plants and forestry plantations within historical Mapuche territories.

Water resources management and institutional framework

The current Chilean Water Code was introduced in 1981, with the development of water markets and tradable water permits as two of its most singular characteristics. In 2013, the World Bank stated that the water management in Chile depends on 43 institutions, which often produces duplications in the execution of functions and problems between the different agencies. In this moment, the creation of a Regional Water Commission to prioritize new infrastructure for irrigation and the attempt to create a Regional Energy Commission to elaborate a Regional Energy Strategy should provide a unique opportunity to advance our knowledge about the interrelations between water, food and energy in the Araucanía region and to try to implement an integrated water management of the Imperial River Basin.

Issue 1: Overcoming poverty: more irrigation under severe droughts and forestry monocultures

Overcoming poverty: more irrigation under severe droughts and forestry monocultures In May 2016, the regional government of the Araucanía mentioned that they are convinced that the best way to overcome poverty in the region is by fostering agricultural sector.

Therefore, the regional government has started an ambitious plan to increase the irrigated area by 100.000 ha by 2022, which would require an increase in water consumption for irrigation. However, ongoing studies show that since 2010 this region has been affected by the most severe drought ever recorded (CR2, 2015), with a growing number of rural families being supplied with drinking water by cistern trucks. On the other hand, many families, rural communities and Mapuche people have found a way to diversify their income by replacing native forest by exotic plantations (mostly Pinus radiata and Eucalyptus globulus), with an open debate about the impact of the exotic forest plantations on surface and groundwater levels (e.g., Little et al., 2009). In late 2015, a Regional Water Resources Commission has been created to analyse the technical and economical feasibility of several new infrastructures (e.g., reservoirs, mini reservoirs, rainfall collectors, irrigation channels, wells for drinking water). This commission is integrated by public agencies, associations of water users and universities.

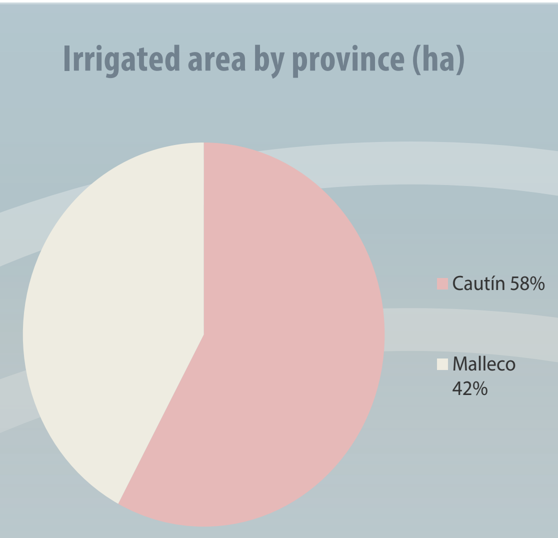

Figure 4: Total irrigated area by administrative province.

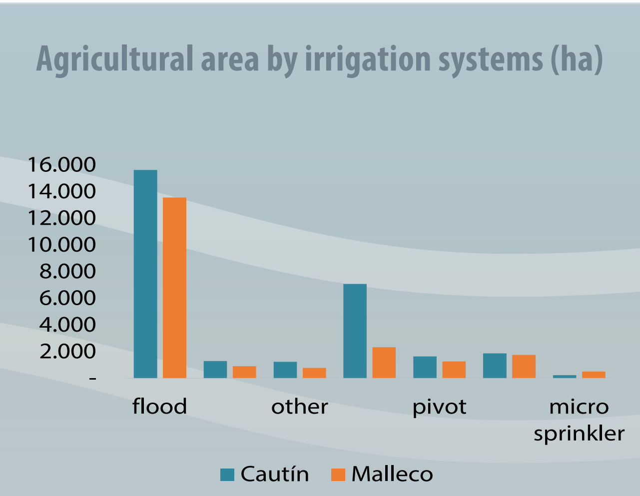

Figure 5: Agricultural area by irrigation systems.

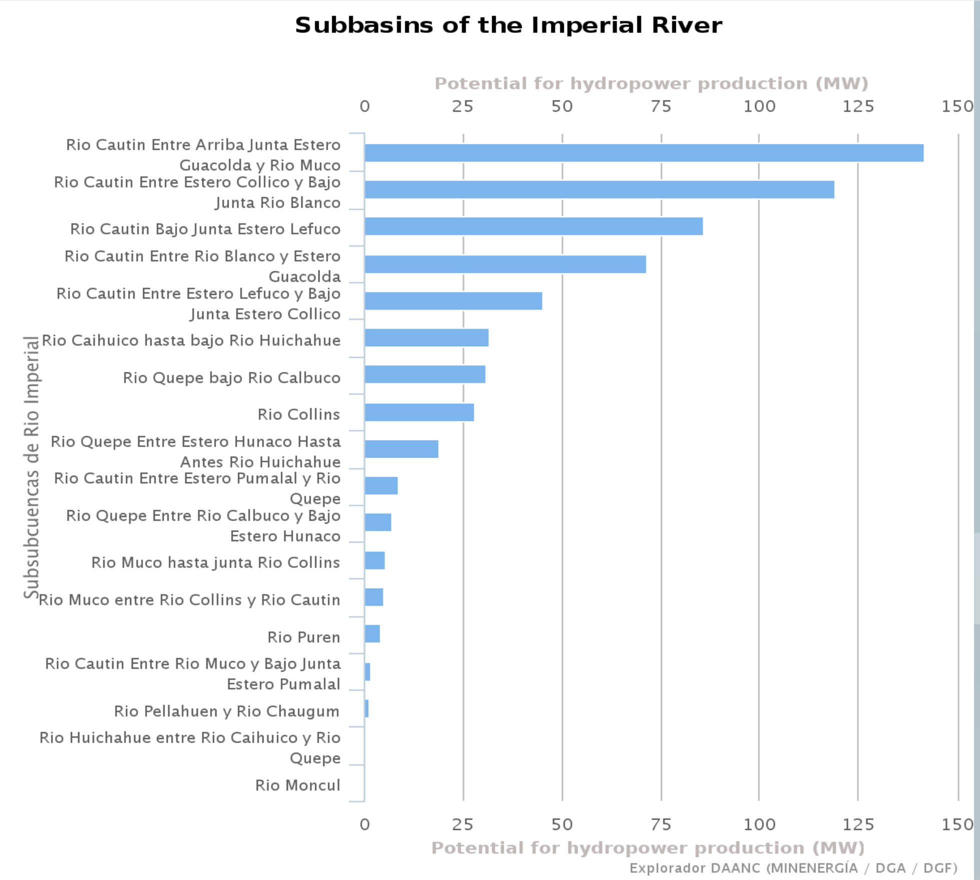

Figure 6: Average discharge constitued as con-consumptive water right in the Imperial River Basin (m³/s).

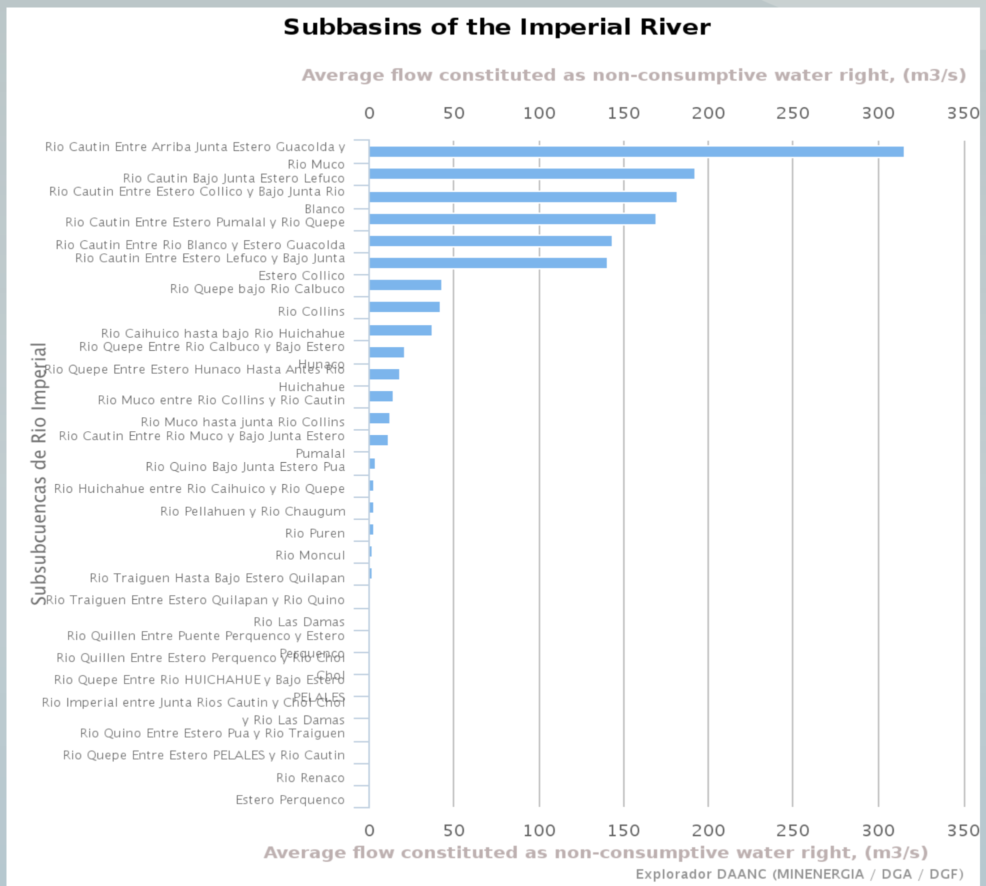

Figure 7: Potential for hydropower production in the Imperial River Basin.

Issue 2: Hydropower production in harmony with tourism, Mapuche communities and information asymmetry

Traditionally, the energy sector in Chile has relied on thermal and hydropower energy generation. However, recent opposition to hydropower projects has led to more emphasis on renewable energies. In particular, the high value of the Araucanía landscape for tourism sector and the presence of Mapuche communities have recently stopped some important hydroelectrical projects. Chile was one of the first nations in Latin America to set long-range targets for clean energy generating capacity. Today, the mandate stands at 20% of renewable energy generation by 2025 and 70% by 2050. To overcome the social opposition to these projects, there is a strong need for generating public information in areas where hydropower projects are more likely to be built. Such information should be easily available for all actors involved in hydropower development, but access to information about the territory usually presents important asymmetries. Hydropower companies develop studies aimed at identifying and mitigating environmental impacts through consulting, whose information only reach the community when it enters the Environmental Impact Assessment system (SEA). While the community can effectively access to those studies, reports are usually lengthy, making them difficult to review. Finally, affected communities usually distrust the information contained in those studies.

Native woodpecker Rucamanque

Nuco [ave]

Copihues

Acknowledgments

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Nexus Timeline: The Imperial River Basin in Chile

Events · Projects · Statistics · Agreements

- **600** – The Pitrén culture is established between BioBio River and Llanquihue Lake, and started growing corn and potatoes
- **1000** – The Mapuche culture begins in the Araucanía region
- **1536** – First contact with Spanish conquerers. Start of the Arauco War
- **1818** – Independence of Chile. End of the Arauco war (282 years)
- **1825** – Tapihue Parlament agrees to the statute governing relations between the Chilean republic and the Mapuche
- **1861** – Start of the Occupation of Araucanía or Pacification of Araucanía
- **1881** – Temuco, the regional capital, is founded
- **1883** – End of the Occupation of Araucanía or Pacification of Araucanía. Start of European immigration
- **1889** – First oil imports to Chile
- **1920** – Oil overtakes coal as the main source of fuel
- **1930s** – Construction of the **CHUFQUEN IRRIGATION CHANNEL** (10000 ha)
- **1943** – Creation of Endesa electricity company
- **1950** – Construction of the **El Castillo reservoir**
- **1960s** – Construction of **Pillanlelbun-Imperial irrigation channel** (2 500 ha)
- **1962** – Start of Chilean Land Reform
- **1963** – Feasibility study of the **Lautaro-Victoria Traiguén irrigation system**
- **1968** – Start of the "big drought"
- **1969** – Start of the "big drought"
- **1970** – Intensification of Chilean land reform (Allende's government)
- **1970s** – Creation of the **Perquenco and Popeta irrigation channels** (1800 ha)
- **1970s** – Construction of Quepe Norte and Quepe Sur irrigation channels (5 500 ha)
- **1970s** – Population of Temuco 88 000 inhabitants
- **1973** – End of Chilean land reform
- **1974** – New Forestry Law DL 701, promoting forestry development in Chile and establishing forestry incentives
- **1975** – Creation of the National Irrigation Commission (CNR)
- **1978** – Creation of the National Energy Commission
- **1981** – New Water Code introduces water rights market for allocation of water resources
- **1982** – Electricity Act
- **1985** – New Law 18.450, promoting private investment in irrigation and drainage works
- **1998** – Modification to DL 701 (Law 19.561), encouraging smallholder afforestation and fragile and degraded soils and land reclamation practices
- Start of the most important drought of the 1990s
- **1999** – End of most important drought of 1990s
- **2002** – Population of Temuco reaches 250 000 inhabitants, while the number of people living in the Araucanía region was 869 535
- **2007** – New non-conventional renewable energy law (Nº20.257)
- **2009** – Creation of the Ministry of Energy
- **2010** – Earthquake, 8.8 on the richter scale
- **2011** – 10 500 families supplied with drinking water by cistern trucks
- **2012** – National Strategy of Energy
- **2013** – The incentive system provided in DL 701 expires
- **2014** – 23 000 families supplied with drinking water by cistern trucks
- **2014** – 5.8 million Euro spent on cistern trucks in the Araucanía
- **2015** – "Energy 2050" Policy
- **2016** – People living in the Araucanía region: 989 798

Magdalena River, by Juansecanencio

The Magdalena River Basin

As the biggest river in Colombia, the Magdalena River has a length of 1,613 km and a difference in altitude of 3,685 m. It flows through 11 departments from the south to the north of the country, converges into the Caribbean Sea while passing the city of Barranquilla and then converges into Cartagena Bay through the Dique Channel. The Magdalena River is the largest navigable corridor of Colombia. The basin covers an area of 266,500 km^2, which is 23% of the territorial area of Colombia, and has abundant water resources with an annual mean runoff of 234,7 billion m^3. The Magdalena River basin is located in a tropical region near the equator. The weather characteristic of the basin is mainly related by topography.

As the core area for politics, economy and culture in Colombia, the Magdalena River basin accounts for 77% and 85% of the country's population and GDP respectively. The control and development of the basin is of strategic significance for the economic development, social progress and environmental protection of Colombia (Cormagdalena et al, 2013).

Natural Resources and social system

Magdalena River basin is rich in water, soil, hydropower energy, water transport, mineral resources and biodiversity. In terms of biodiversity, this watershed is one of the most important reserves genetic of phyto-animals in the world. The basin has complex and diverse ecosystems. Its main vegetation is a natural secondary forest vegetation, which is followed by economic forest, wetland vegetation, mangroves in estuaries with a forest coverage of 26.36% (Cormagdalena, 2013). Magdalena basin has the following ecosystems: forests, deserts, savannas, and xerophytic and wetland ecosystems (IDEAM-Cormagdalena, 2001). The basin is rich in flora and fauna. There are 230 kinds of timber species, including pine, eucalyptus, cedar, nagkassar, olive, etc. There are 2,735 animal species, including 1,721 bird species (20% of the world bird species), 54 amphibian species, 506 reptile species and 454 mammal species (Cormagdalena et al, 2013).

The annual water supply in the Magdalena basin is 271.049 Mm^3 for an average year and 119.917 Mm^3 for a dry year. The national water demand is 35.987 million m^3. The agriculture sector uses 16.760,33 million m^3, equivalent to 46,6% of the total volume of water used in the country. The power generation sector participates with 21,5%, the livestock sector with 8,5% and the domestic use with 8,3% (Figure 1) (IDEAM, 2014).

In terms of power generation, the installed capacity in the basin is 35.440 MW, which accounts for 38,6% of the country's total. The installed capacity on the main stream of Magdalena River is 6.821 MW, which accounts for 19,2% of the basin (Cormagdalena et al, 2013). Table 1 shows the installed effective power generation capacity of some hydroelectric power plants in the basin.

Hydroelectric power plants	Capacity / Effective (MW)
Betania	540
El Quimbo	396
Guatape	560
San Carlos	1.240
Porce II	405
Porce III	700
Prado	46
Salvajina	285
Sogamoso	820
Miel I	396

Table 1. Hydroelectric power plants in the Magdalena river basin. Reference: UPME, 2015.

The basin is rich in mineral resources. Colombia has the largest coal reserves in Latin America, mainly distributed in the Magdalena River basin. Oil and gas resources in the basin are mainly distributed in the upper and middle reaches of the Magdalena River. Other minerals such as phosphate, gypsum, iron-limestone, limestone, emerald, precious metals, copper, nickel, marble and granite are distributed throughout the whole basin.

The Magdalena River is a shipping artery that connects Colombia's main inland production and consumption with centers within the coastal area. The navigable length of its main channel and tributaries is 2.770 km in total.

The Magdalena river influences the life forms of the Colombian territory; and it has also allowed domestic and industrial production practices at local and regional levels, from fishing to mining and from livestock to agriculture. The river connects territory, populated islands on the coast, in the plains or alluvial plains, in the mountains or in the forests. The river has helped to strengthen the cultural background of the country (Bocarejo, 2016).

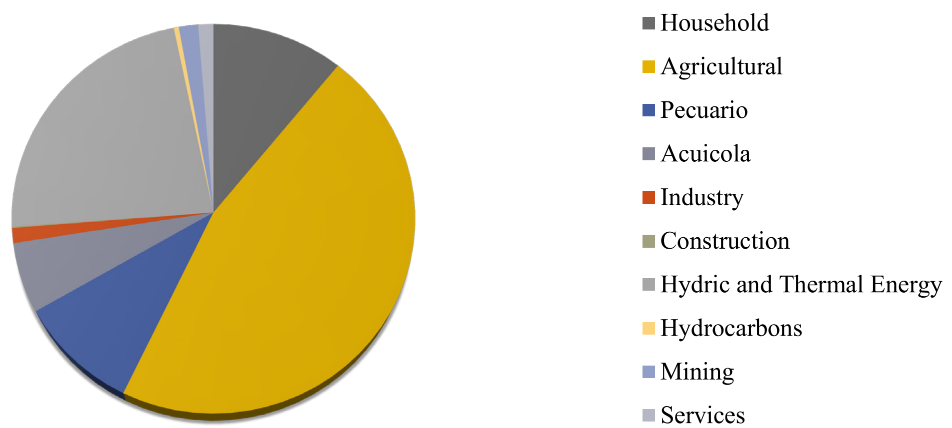


Figure 1. Water uses in the Magdalena river basin.
Reference: (IDEAM, 2014).

The basin covers 19 departments and the capital district of Bogota, with 728 municipalities. The basin has a population accounting for about 77% of the total population in Colombia, with an average population density of about 130 people/km2 and an urbanization rate of about 77%.

Colombia's regional economic development is unbalanced, with an economic focus mainly concentrated in large cities in mountainous areas with higher elevations or on the coast; small and medium cities and towns and rural areas lag behind in economic and social development, with a high proportion of poor people. Colombia's agriculture mainly includes crop farming, animal husbandry, forestry and fishery, which are distributed throughout the country. Coffee and flowers are the most important agricultural exports (Cormagdalena et al, 2013).

The Magdalena basin is of vital importance in agriculture. In this area, the majority of domestic agricultural products are generated: more than 80% of annual crops in the country, 90% of coffee production, 95% of permanent crops, and more than half of rice, barley, beans, corn traditional, potatoes, cocoa, sugar cane, sugarcane, coconut, oil palm, cassava and plantains. In the basin there has been a change in land use, disfavoring agriculture for the benefit of pastures that are used for livestock (Cormagdalena, 2007) (Figure 2).

Food availability is not a risk to food security because much of it comes from domestic production. However, the problem is the unequal distribution of food caused by inefficiencies in infrastructure and transportation. Significant losses occur in production volumes by not distributing food in a timely and appropriate manner; on the other hand, in remote geographical regions and where agro-climatic conditions are not suitable for food crops, food prices are too high. All this results in lower revenue for farmers and higher prices for consumers (MARD, 2011). In 2008 the National Policy on Food and Nutritional Security was adopted. The aim is to ensure that all Colombians have access to food in a timely manner and in sufficient quantity, variety, quality and safety (Conpes-DNP, 2008).

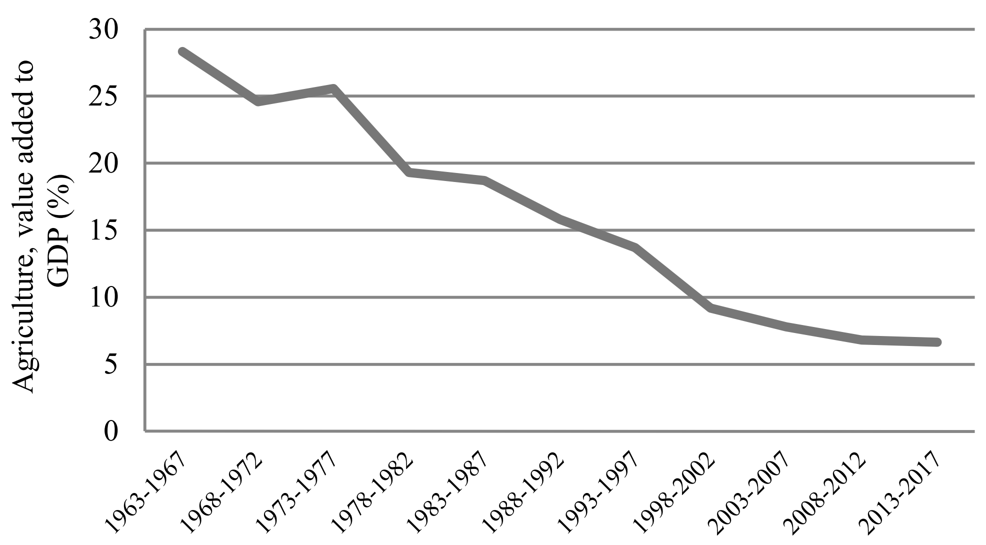


Figure 2. Agriculture, value added to GDP (%) Colombia.
References: FAO, 2015.

Development in the basin

In recent years the basin has improved in shipping, hydroelectric development, construction for flood control, irrigation, and protection of aquatic ecosystem and environment, which has promoted basin economic development and social progress. However, there still exist several problems, such as low comprehensive utilization of water resources, frequent floods, relatively serious soil erosion, bad water quality and water ecology, conflicts over land use and incomplete implementation of comprehensive basin management.

- **Navigation**. The current waterway transport network mainly consists of 887 km downstream the main river Salgar, 114 km of Dique Canal, and 187 km downstream the tributary Cauca River. Among those channels, the 631 km downstream Barrancabermeja and the Dique Canal are channels for transporting thousands of tons. A navigation network connecting the inland with Caribbean coastal urban ports has been preliminarily formed. In 2011, the freight volume in Magdalena River was 2,240,000 t, and passenger volume was 2,110,000 persons. (Cormagdalena et al. 2013). Currently, hydrocarbons, the main freight transported on the Magdalena River, are measured in volume. These come out of Barrancabermeja destined for refining plants in Cartagena or seaports (Asoportuaria, 2013).
- **Hydropower**. The electric system in Colombia is dominated by hydropower. In 2009, hydropower installed capacity was 9.001 MW, taking up 66% of total installed capacity, and hydropower stations were mainly distributed within the Magdalena River basin (Cormagdalena et al, 2013). The net effective capacity of the national interconnected system by the end of 2015 was 16.420 MW. Hydropower contributed to 10.892 MW (Figure 3). The generation expansion by technology type can be seen in Figure 4 (XM, 2015).
- **Irrigation**. In Colombia, there is an underutilization of the best agricultural land and low development level of irrigation infrastructure. Of the total potential irrigated area, 7.6 million hectares in 2011, only 1.086.800 ha, 14,3 percent, have infrastructure for irrigation (DNP, 2011). Irrigation areas are mainly distributed in the river valley of upstream Honda-Betania Reservoir reaches and the surrounding plains downstream of Dique Canal. The area of constructed irrigation areas is 153.896 ha, among which 12 are large and medium irrigation areas with a total area of 145.893 ha, and 75 are small irrigation areas with a total area of 8.003 ha; 72% of large irrigation areas are supplied with pumping irrigation methods (Cormagdalena et al, 2013).
- **Utilization of fishery resources**. Capture fishery is the main food and economic source of 46.000 riverside fishermen. According to 2002 data provided by INCODER (Instituto Colombiano de Desarrollo Rural), freshwater fish production and total yield (including marine fishery) within the basin respectively took up 62% and 18% of the total production and yield in Colombia. La Dorada-Honda, Puerto Boyacá, Puerto Berrío, Puerto Wilches-Barrancabermeja, Gamarra, El Banco, Magangué, Plato, San Cristobal- Canal and Barranquilla reaches are the major fishery resource utilization areas (Cormagdalena et al. 2013).

Colombian imports showed growth for the period 2004-2013, from USD 33.174 million in 2004 to USD 224.91 million at the end the period. Exports were met by imports in 2012 and surpassed by them in 2013 (MADR-FAO, 2015) (Figure 5).

In 2013 Vietnam remained as the country's largest trading partner, and with Chile and Ecuador, accounted for 52% of total Colombian imports (Figure 6). Colombian exports are concentrated in the Free Zone of Cartagena, where the product (tuna) is sent to international markets (Figure 7). With regard to aquaculture, the main export product is tilapia to the United States. In the period between 2004 and 2013, an estimated 90,863t of fish were caught in the Magdalena basin (MADR-FAO, 2015).

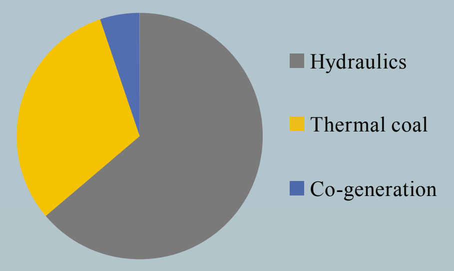


Figure 3. Composition of interconnected system generation 2015 Colombia. References: (XM, 2015).

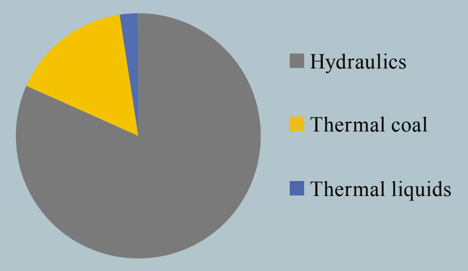


Figure 4. Generation expansion by technology type (MW) (2014-2020) Colombia. References: (XM, 2015).

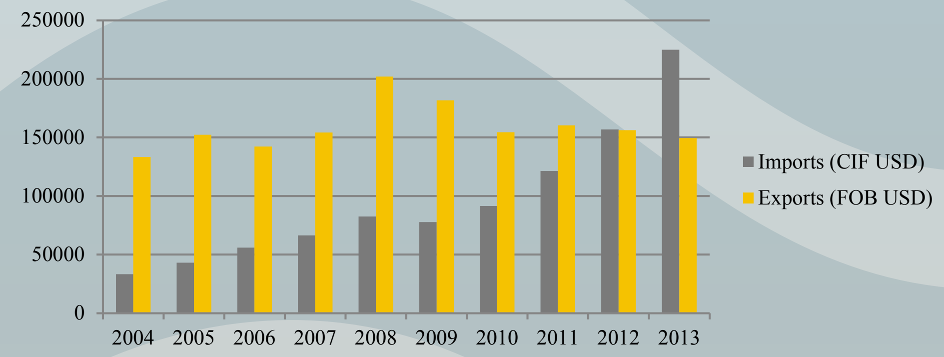


Figure 5. Evolution of imports and exports of fisheries (2004-2013). Colombia.
References: Trade Map, ITC Calculations based on UN Comtrade Statistics 2014. Elaboration. FAO 2014.
CIF (Cost Insurance and Freight)
FOB (Free On Board)

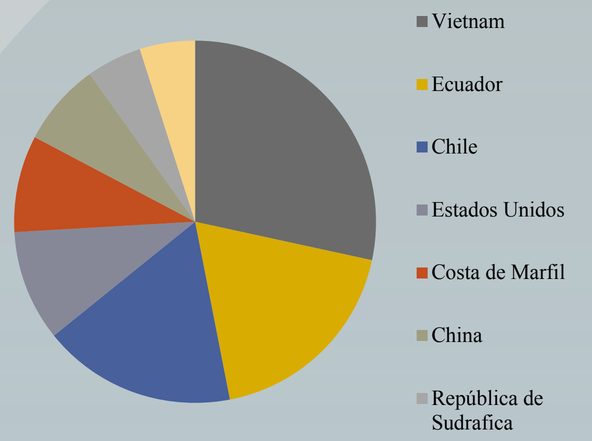


Figure 6. Participation % principal sources of imports of fishery products 2013 Colombia.
References: Fuente Legiscomex 2013. Elaboration FAO 2014.

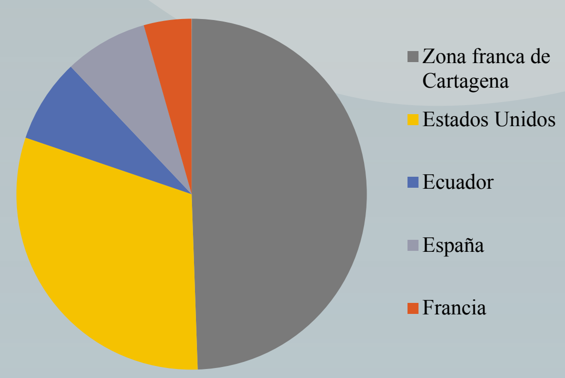


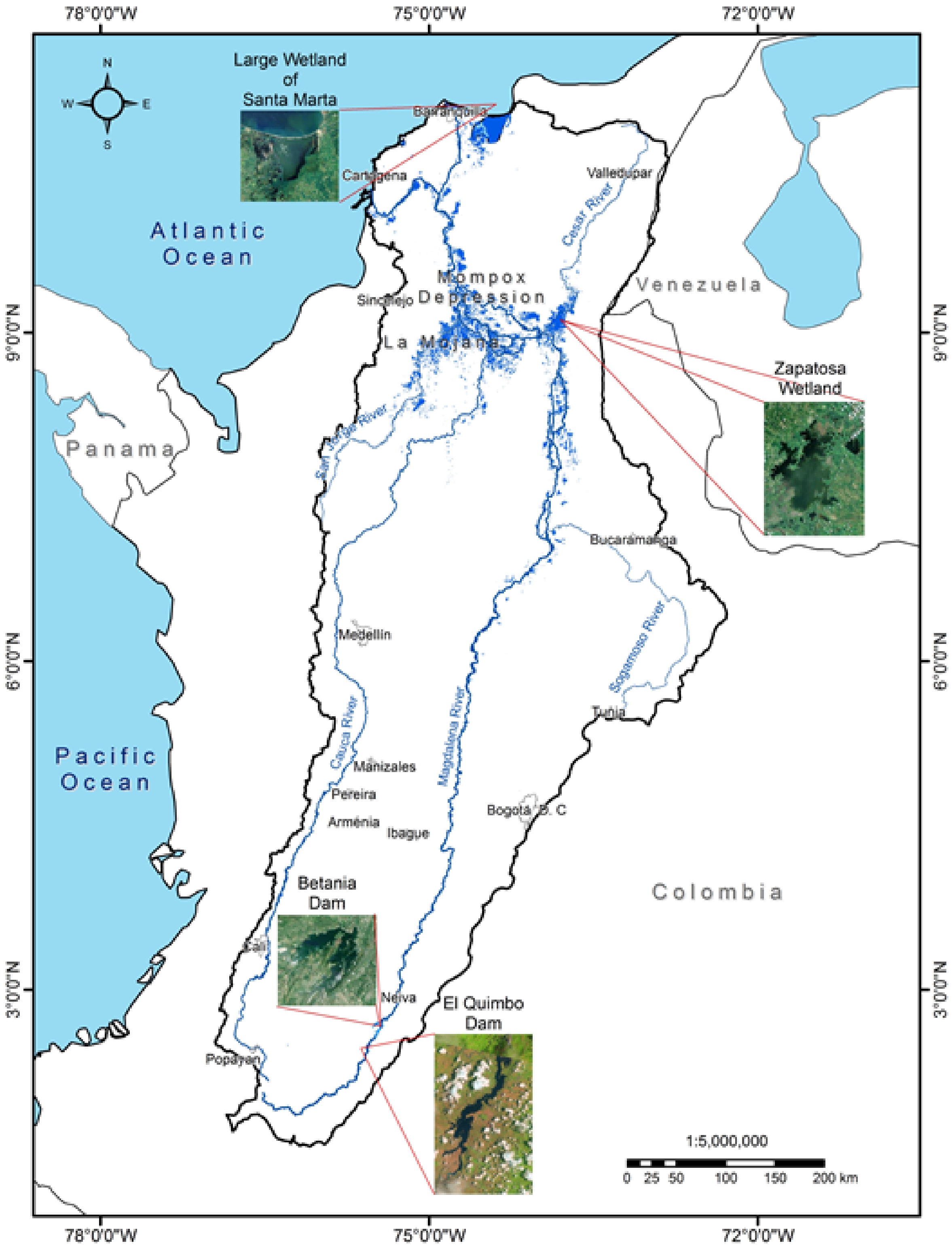
Figure 7. Participation % main export destinations of fishery products 2013 Colombia.
References: Fuente Legiscomex 2012. Elaboration FAO 2014.

Strategies

The Magdalena River basin has an important strategic position in the economic and social development of Colombia. Cormagdalena, as the leading institution for the management of the Magdalena River watershed, has the responsibility of the development and protection of the water resources of the river related to energy supply, food supply and regionally economic and social sustainable development in the country (Cormagdalena et al. 2013).

The basin is also faced with problems such as climatic change, increased pressure for ecological environmental protection, etc. In order to adapt for the sustainable development of Colombia in the future, it is necessary to guarantee energy supply, food supply and ecological safety in the country for the sustainable utilization of water resources. Some strategies are presented:

1. Strengthening environmental protection and maintaining river health (e.g. Water quality, biodiversity)
2. Rational use of resources
3. Promoting comprehensive utilization of water resources and comprehensive management of the basin
4. Optimizing and advancing the construction of a comprehensive transport system
5. Establishing a robust system for disaster mitigation
6. Rationally developing and utilizing hydropower resources
7. Institutional strenghtening of the integrated management of resources
8. Consolidating and strenghtening the governance and the governability of the basin
9. Promoting the economic and social development at a local level



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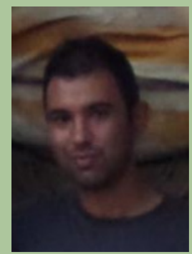

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Navegando en la mañana, by Edgar Allan Rodríguez

Entre el río y el mar, by Carlos Andrés Cordero

Nexus Timeline: The Magdalena River Basin in Columbia

Events · Projects · Statistics · Agreements

1501 – Rodrigo de Bastidas named it Rio Grande de la Magdalena (Hannibal Noguera, 1980, vol 1.)

1590 – Legal regulation of the Magdalena river transport

1654 – The Dique Canal was opened, allowing navigation from Calamar (Bolivar) to Cartagena

1922 – The Barrancabermeja refinery enters into service

1981-87 – The Betania hydroelectric project was the first infrastructure directly associated with damming of the river basin

1994 – Laws 142 and 143 establishing the separation of the electric sector generators, transmitters and distributors

Article 331 of the Constitution of Colombia and the Law 161 of creating Cormagdalena

Population in the Country: 36.854 millions
GDP: 81.7 billion USD

2000 – Population in the Country: 33.6 millions

Management Plan and Watershed Management of the Río Grande de la Magdalena.

2003 – Population in the Country: 41.849 millions
GDP: 94.68 billion USD

2008 – Social Conpes 113 2008 document defines food and nutritional security

GDP: 233.8 billion USD

2009 – Management Plan Cauca Magdalena Basin

2011-2013 – The Quimbo Hydroelectric Project is built

2014 – GDP: 377,7 billion USD

Master Plan Development of the Magdalena River

2015 – Population in the Country: 48.278 millions

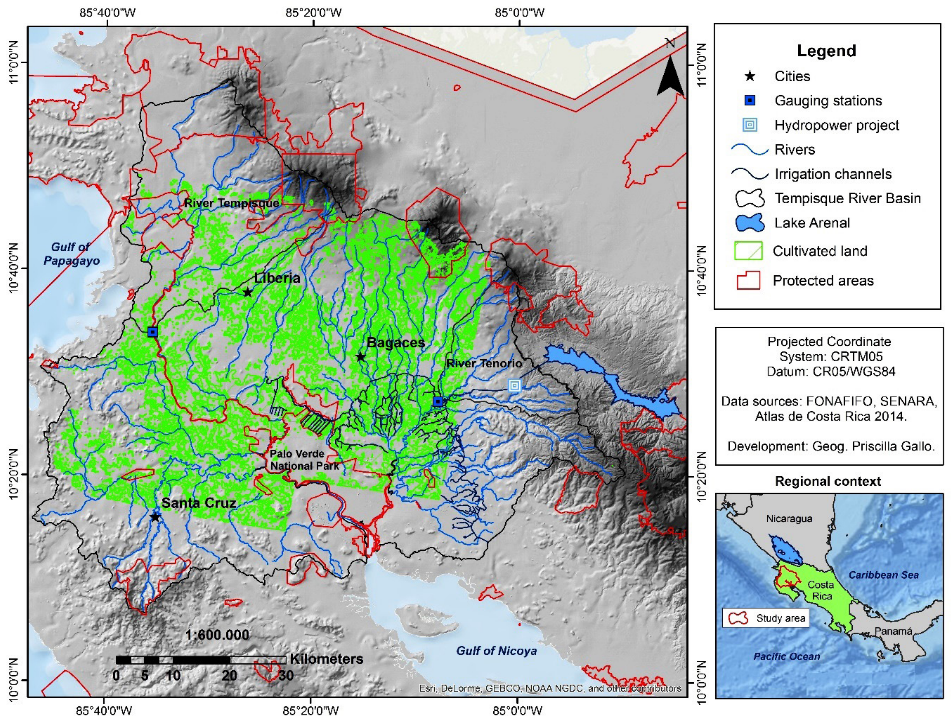
Lake Arenal located in the upper Bebedero catchment from an aerial perspective, by Christian Birkel

The Tempisque-Bebedero catchment system: energy-water-food consensus in the seasonally dry tropics of northwestern Costa Rica

I. Study catchment characteristics

The Tempisque-Bebedero total catchment area is around 3400km2 (Map 1) with the Tempisque being the third longest river in Costa Rica (144km). The continental divide is denoted by the volcanoes (from NW to SE) Orosí, Cacao, Rincón de la Vieja (1916m a.s.l., highest elevation), and Miravalles and Tenorio form the catchment boundary in the east. However, water from the Caribbean slope is imported into the catchment for hydropower production and irrigation (Map 1). Lake Arenal would naturally contribute to the Caribbean lowlands, but was artificially enlarged to 85.5km2 (three times its original size) for greater storage in 1979. A relatively low mean elevation of 260m a.s.l. and a mean slope of around 6° characterize the catchment system. The drainage density (total stream length/total drainage area) is also relatively low compared to the rest of the country (0.5 at a scale of 1:200,000). The latter results in rivers with a low transport capacity, particularly in the lowlands, and the main channel of the Tempisque slowly meanders towards the Gulf of Nicoya.

The Tempisque-Bebedero catchment system is characterized by a seasonal tropical climate (Aw – Köppen-Geiger updated world climate classification) with a marked dry and wet season cycle and small temperature variability over the year (Peel et al., 2007). The dry season typically lasts from December into April with virtually no rainfall. After a short transition period, rains reach a first maximum in May/June. This first maximum is followed by a dry period of 2-3 weeks in July, usually referred to as the mid-summer drought (Magaña et al., 1999). The rain maximum is reached in October, related to the position of the Intertropical Convergence Zone (ITCZ). The river flows reflect the seasonal climate. Mean flows from 1973 to 2003 at Guardia, Tempisque and Bebedero, Tenorio gauging stations (see spatial reference in Map 1) were 24.6 and 9.3m3/s, respectively. However, the lowest dry season flows measured (late April) were as low as 2.6 and 2m3/s, respectively. The mean water yield of 5.3L/s per km2 at Guardia is among the lowest in the country. Such a marked seasonality with relatively low water yields has historically been a challenge for water resources management in the northwestern region of Costa Rica. The overall mean annual water balance for the catchment system is precipitation of around 1800mm/year; MODIS satellite-derived actual evapotranspiration of around 1100mm/year and a resulting runoff of 700mm/year.



Map 1: The Tempisque-Bebedero catchment system in a regional context and main features related to water resources management, such as hydropower generation, irrigation channels, river network, protected areas and Palo Verde wetland National Park (developed by Priscilla Gallo).

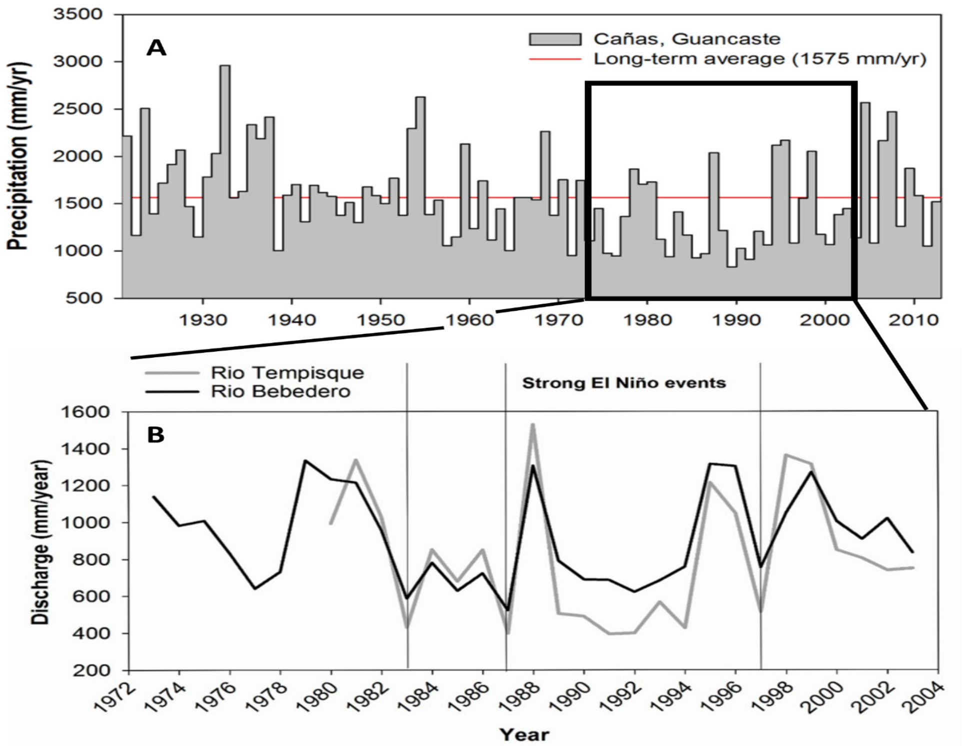


Figure 1: A) Long-term mean annual rainfall variability in mm/year at Cañas rain gauge close to Bagaces (Map 1) located in the Bebedero part of the catchment system (data from Werner Hagnauer's monitoring station in Cañas, Guanacaste (1920-2015)). In contrast, B) Annual discharge in mm/year for the Tempisque and Bebedero Rivers showing strong inter-annual variability with the driest years related to strong El Niño events (1983, 1987 and 1997) and the maximum flows indicating La Niña events (http://ggweather.com/enso/oni.htm) and the indirect influence of tropical cyclones (1988 – Category 5 Hurricane Gilbert and category 4 Hurricane Joan).

Additionally, in a marked hydrometeorological seasonality (rainfall and river runoff exhibit dry and wet season cycles), the Tempisque and Bebedero Rivers show a pronounced year-to-year variability in their total runoff volumes synchronous to rainfall (Figure 1). This variability can be related to regional circulation patterns such as the El Niño Southern Oscillation (ENSO) and also to indirect effects of tropical storms (Waylen, 1996). The strongest historical El Niño events (1983, 1987, 1997) are reflected in the lowest annual runoff (~400mm/year); the strongest La Niña-events, in combination with strong storms, are reflected (for example, 1988) in the highest recorded runoff volumes (>1200mm/year). The latter's highest volumes exceeded the drier years more than three times, which has resulted in floods across the low relief plains, before reaching the natural floodplain wetland areas (Palo Verde National Park). In Figure 1A and B, it becomes evident that dry years tend to cluster and persist for up to five consecutive years (for example, from 1989 to 1994 in relation to moderate El Niño conditions, there were a series of very low annual rainfall, Figure 1A), followed by one or maximum two wet years. Such natural variability represents a challenging scenario for water resources management and associated hydropower and food production because the water resources vary significantly on a seasonal and inter-annual basis. Any management and decision-making should therefore consider taking action at least on a mid to longer term temporal scale (> 5 years).

Marked seasonal and inter-annual variability of water resources in the Tempisque-Bebedero catchment system dictates that management and decision-making related to conservation, hydropower and food production should be applied using a time frame beyond 5 years.

The Guanacaste region in northern Costa Rica has long been an important bridge in Central America for imports and exports of particular agricultural products. Historically, the main rivers (Tempisque and Bebedero) were used for transportation dating back to pre-Colombian times (Chorotega, Corobici, and Aztecan native people inhabited the region). During colonial times, the region, which coincides to almost 40% of the Tempisque-Bebedero catchment system (Map 1), was transformed into a large-scale, hacienda-type cattle farming area. Such a development was based on the deforestation of mainly tropical dry forests and their subsequent conversion into pasture in the lower parts of the catchment system. More recent land use transformations since the 1950s have included an expanding crop production, such as rice, sugar, beans, melon and to a lesser extent coffee (~940km2 of cropland area in 2010 or 28% catchment area). In 2015, 326,953 inhabitants lived in the Guanacaste region (4,757,606 total or ~7% of the Costa Rican population), which is mainly comprised of rural communities, apart from the province capitol Liberia (~57,000 inhabitants). The average population density of 32.2 hab/km2 is low compared to the national average of 84.2 hab/km2. The Human Development Index (HDI) for Costa Rica increased from 0.605 in 1980 (50th world ranking) to 0.766 in 2014 (69th world ranking). The Guanacaste region averages an HDI of 0.768 in 2015 with the district of Liberia exhibiting an HDI among the highest of the country (0.839), stating a relatively high quality of life with access to education, health services and economic resources.

II. The study catchment's role for the national food and energy production

1. Food production

Since independence in 1821, Guanacaste has played a critical role in national food production (Subirós, n.d.), mainly supplying grains and meat. The Tempisque-Bebedero catchment system has experienced a significant increase in land used for agriculture and crops that depend on irrigation. The area used for crop agriculture (pasture excluded) in the catchment increased from 0% in 1950 to 4.4% in 1974, 24.7% in 2000 and 27.8% in 2010. A total of 940km2 was used for crop production in the catchment in 2010 (Map 1). Irrigated agriculture started in the 1970's with the construction of the first phase of the Tempisque-Arenal Irrigation District (TAID – 60km2) and comprised around 130km2 in 2000. The TAID is currently increasing the total length of 366km of irrigation channels. In the 1980's, the agricultural model finally shifted from a more subsidence-oriented to an industrial and export-oriented model, increasing productivity and also diversification. The latter shift was mainly driven by the insertion into international markets, which culminated in the Free Trade Agreement with the USA in 2009. Currently, the catchment comprises a diverse mosaic of traditional and non-traditional products, such as sugar cane, rice, melon, watermelon, coffee, corn, beans, aloe, and citrics, among others, plus a significant extension of terrain dedicated to livestock (MAG, 2011).

Despite changes in the agricultural model, production in the region deeply relies on processes with low added value and faces obstacles to incorporate technological resources (Molina, 1991; SEPSA, 2004). As a consequence, some of the activities have a noticeable impact on key ecosystems, such as the Palo Verde Wetland National Park, affecting the overall water quality and quantity (Whealan, 1989; Bach, 2006). Legal concessions to extract water from the Tempisque river exceed the average dry season flow, and unknown but suspected illegal abstractions additionally affect the river ecosystem (La Nación, 22/05/2016). However, the government (Ministry for the Environment and Energy) does not have the capabilities to monitor and regulate the legal and illegal extractions. The latter governance issue poses a high potential for conflicts among agricultural and livestock water users. To date, this structural challenge has been approached by projects such as the TAID (Zúñiga, 1993), seeking to increase the water availability and consequently a larger spatial distribution. However, recent water shortage episodes and increasing conflicts among water users now lead to efforts aiming for a more integrated water resources management approach, particularly because new actors and users (e.g. tourism) settle in the area. For example, the government of Costa Rica released in 2015 the Integrated Programme for Water Provision in Guanacaste (PIAAG, according to its initials in Spanish). This effort (with an initial budget of $4 million) focuses on four pillars: a) water security for communities, b) food security, c) ecosystem services, and d) sustainable management.

On a national scale, the agricultural sector only makes up around 6% of the national PIB compared to a 19.7% coming from industry and an expanding service sector with 74.3% in 2015. At a relatively stable average unemployment rate of 8.7%, Costa Rica exported a total of US$ 9.756 billion in 2015. The main agricultural export products are banana, pineapple, coffee, melon, ornamental plants, sugar, beef and seafood going mainly to the USA (38.4%), the Netherlands (6.2%), Panama (5.3%), Nicaragua (4.4%) and Guatemala (4.1%).

2. Hydropower generation

Costa Rica relies on renewable energy sources (around 97%) and might even be able to reach 100% renewable in a near future. The national energy matrix in 2015 was composed of 66% hydropower, 16% wind, 14% geothermal, 2% biomass, 0.02% solar, and only around 2% thermal (diesel combustion) energy was used (Figure 2). The year 2015 was also a year of records for Costa Rica in that the country ran on 100% renewable energy for 94 consecutive days (The Guardian, 30/03/2015). This world record was established despite 2015 being an extremely dry year on the Pacific slope, particularly in the study catchment due to a strong El Niño event. The Costa Rican renewable energy matrix is mostly possible due to a small population, no major industries, and the resulting relatively low energy consumption in combination with physical factors such as the topographical gradient, abundant rainfall, and active volcanic activity. However, the hydropower sector as the major contributor to the nation's energy matrix is also vulnerable to climate change, resulting in long-term hydro-meteorological droughts (Giorgi, 2006).

The Tempisque-Bebedero catchment system is home to the country's largest hydropower project Lake Arenal (Map 1). Lake Arenal contributes around 17% to the national power grid (installed capacity of 157MW), and the biggest geothermal projects (The Miravalles Geothermal Field opened in 1994 and contains five plants generating up to 163 MW; the Pailas Geothermal Power Plant established in July 2011 produces a total of 55MW) are also located within the study site close to the Rincón de la Vieja and Miravalles volcanoes.

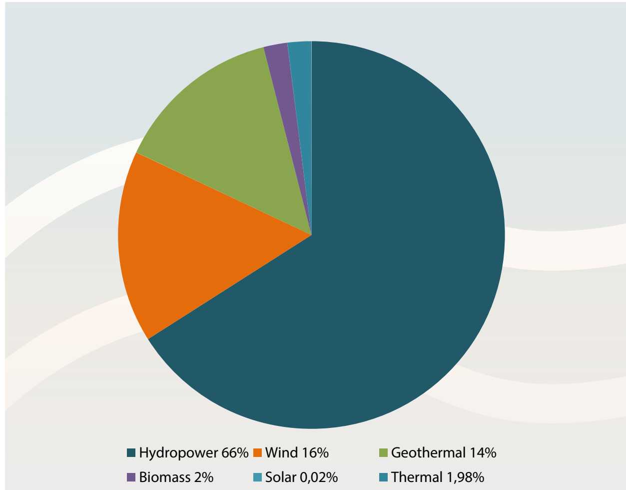


Figure 2: The national energy matrix in 2015. Almost 98% renewable energy was generated, despite a prolonged dry period affecting the Pacific slope region.

III. Increasing vulnerability affects food security

Cumulative environmental and socio-economic processes are co-evolving with recent political dynamics that are affecting the stability of the food and energy production models. The main observed changes are the following:

- Climate variability (increasing temperatures and water scarcity during prolonged dry seasons)
- Agro-industrial model (increasing productivity and diversification of products according to international demand and not necessarily based on local capacity)
- Energy production (increasing number of small scale hydropower projects)
- Land use changes (increasing urbanization)
- Economic sector (tourism is now a major player in the area with increasing large scale hotel and resort projects)

Within this context, more people will be demanding access to a resource that is already being affected in terms of quality, quantity, and distribution (Calvo, 1990; Guzmán-Arias, 2013). However, the intense land use change, considered as the main underlying driver, is not adequately regulated across the region. Such lack of regulation is increasing the potential for local and sectored conflicts in the area, as well as at the national level. Local cases of conflict, such as in the case of the community of Sardinal (Navas and Cuvi, 2015), mainly between the local population and the touristic sector, is an example of how important it is to develop a comprehensive approach for truly integrated water resources management in the region.

IV. Reconciling future economic development and water resources management – challenges ahead

The Tempisque-Bebedero catchment system has been the scenario of a rapid economic reorganization during the past 30 years. Traditional and new economic activities are still facing challenges regarding the implementation of an adequate co-evolving model. Local and regional development initiatives also need to be integrated into a nationwide development strategy, which is increasingly more connected with global markets. Natural resources protection and social wellbeing are cornerstones in the achievement of a more sustainable and resilient development (Pelling, 2011). Some structural challenges will need to be addressed with more clarity in the near future to understand the current and potential changes of the natural dynamics in the basin in order to improve the socio-economic planning in the coming decades. The study catchment is located in one of the most vulnerable regions to climate change in the country (Hidalgo and Alfaro, 2012). As pointed out by the recently approved Sendai Framework for Action on Disaster Risk Reduction (United Nations, 2015), the starting point for reducing the impacts of disaster risk and climate change effects is to better understand the drivers behind the risk. This is a basic principle which still needs to be promoted in the region through more investment in relevant research and projects that enhance the interface between science and practical applications to advance towards a multi-sectored development, which considers the different needs of actors, communities, and institutions.

Across Latin America most of the development goals have been created in isolation. The recent governmental and citizen awareness related to socio-economic challenges in the region invoke an urgent and comprehensive approach to tackle the development challenges in Guanacaste. The formulation of common initiatives (NEXUS) between different sectors such as water, environment, agriculture, and energy will be crucial for improving the effectiveness of water resources management (Hoff, 2011). Despite the obvious connection between these sectors, in practice there is little interaction, especially at the local level. A more committed political action plan will be required to balance this situation and to promote an institutional culture of cooperation between public sectors.

There is an urgent need to enhance environmental protection and technological transfer in the Tempisque-Bebedero catchment while securing water supply and reducing the impact of economic activities on ecosystems and vulnerable livelihoods. Most of the already established productive activities can likely not be replaced in the short term; cultural, technical and political factors constrain a swift transformation of practices that may not be sustainable considering the natural conditions. While a long term development strategy is slowly being implemented by different actors, parallel processes should be promoted in order to reduce the impact that some activities have over common goods, especially the water supply (Jimenez et al., 2001). Environmental degradation and lack of technological support are at the core of poverty and vulnerability to climate impacts (ISDR, 2009); currently, there are many alternatives to enhance this agenda through local action and capacity, public – private alliances, law enforcement and increasing the investment in institutional capacity building.

Lake Arenal hydropower project from an aerial perspective, byChristian Birkel

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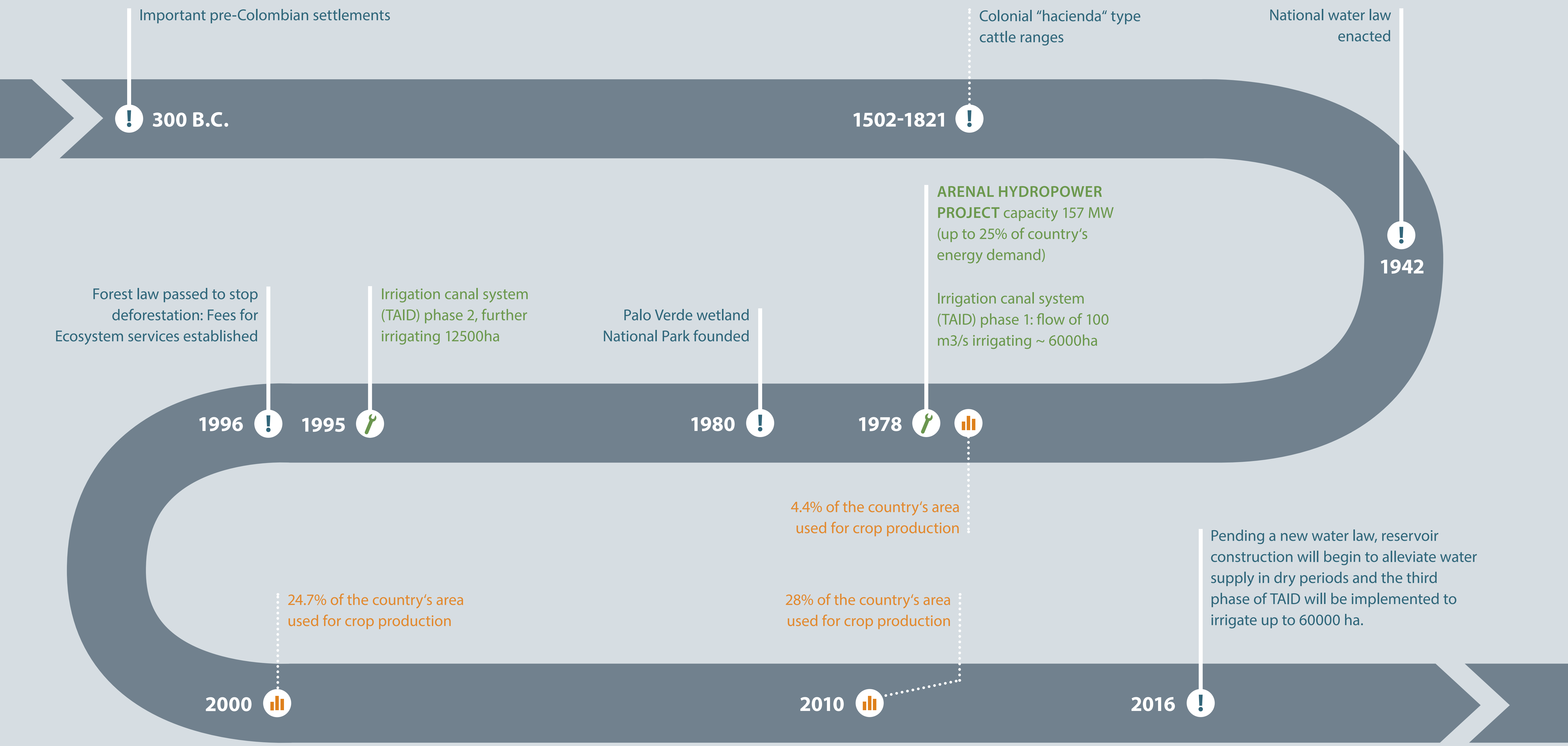
Events Projects Statistics Agreements

Nexus Timeline: The Tempisque-Bebedero catchment in Costa Rica



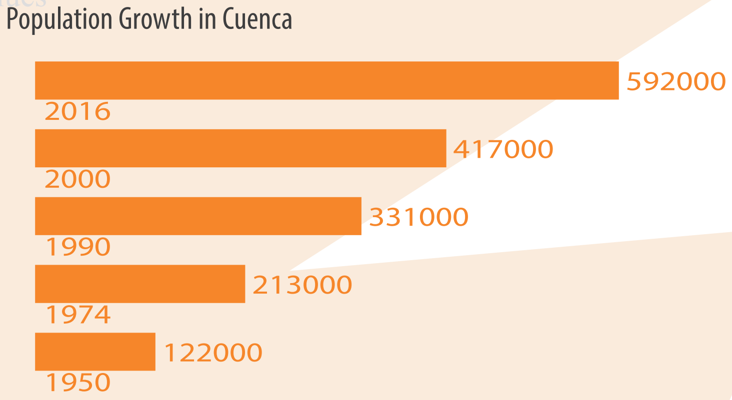
Cajas National Park, by Delphine Ménard

Integrated water resources management in an Andean mountain basin: the case of the Machángara River

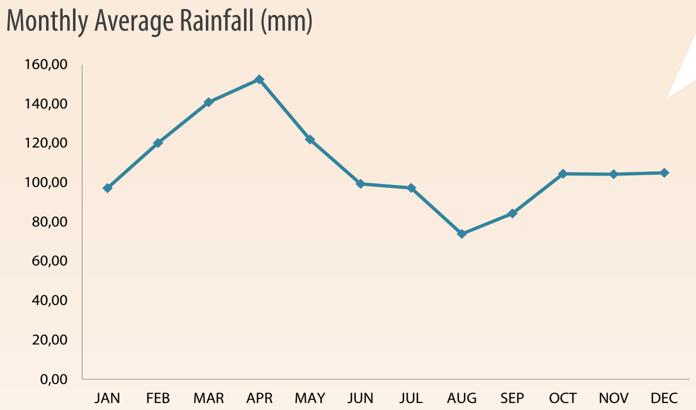
The Machángara River basin is located in the southern Ecuadorian Andes. With 325 Km2, a mean elevation of 3400 m asl, and 1100 mm of mean annual precipitation, the Machángara River drains to the Paute River and later into the Amazon basin. From the headwaters to the basin outlet, there is a transition from the páramo ecosystem (4400 to 3200 m) to mountain forests and grasslands (3200 to 2800 m), to agricultural areas and finally to urbanized areas (2500 m). Around 50% of the basin is covered by tussock grasses with disperse spots of Polylepis forest (1020 ha), wetlands and natural lakes (1930 ha), which constitute the Páramo ecosystem (Machángara River Basin Council, 2012). While the Páramo is of major importance for discharge regulation, it is highly vulnerable to climatic change conditions. The Machángara River basin supplies 304 hm3 /year of water for hydropower production, irrigation, drinking water systems and industrial users. Due to this fact, this basin is economically important for the region. Two hydroelectric projects, i.e. Saucay and Saymirin, generate 39.5 MW of electricity. In the middle part of the basin, there is livestock and agricultural production and small proportions of native forest timber production. In the lower part of the basin, 840 l/s are sent to the Tixán drinking water treatment plant that supplies part of the water needs of the city of Cuenca (3rd largest city of Ecuador) and for agricultural and industrial use. Thus, there is increasing pressure on the Machángara water resources. More importantly, in the future, such pressure will be increased under land use and climatic change conditions, as well as population growth.

Sustaining food production

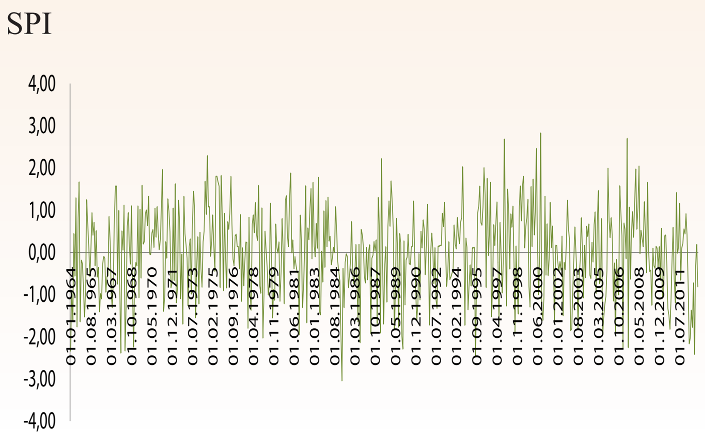
While oil represents around 40% of exports, the Ecuadorian economy also depends on the agricultural sector. In the highlands, agricultural production is concentrated in small-scale farming, and general productivity is low. In the Machángara basin, there are 3 irrigation systems, namely the Machángara, Checa-Sidcay and the Sociedad Ricaurte systems. These systems are located downstream of the hydropower plants, and Cuenca is the main market for their products. Throughout the years, the irrigation systems have been improved to reduce distribution losses (by lining irrigation channels), to reduce application losses (by implementing sprinkler and drip irrigation), to avoid the soil degradation caused by the intensification of agriculture, and to implement agroecological farming systems. These ongoing actions have both improved the water use efficiency of the irrigation systems and increased food security. Furthermore, they have reduced labor costs, and it is expected that they will help increase the net income of small-scale farmers. Supply depends on pumping water from the Nile for irrigation of cultivated land, using more than 560 pumping stations and 1600 pumping units (Feytan et al. 2007)



Month	Average rainfall (mm)
JAN	97,09
FEB	120,04
MAR	140,76
APR	152,38
MAY	121,85
JUN	99,28
JUL	97,20
AUG	73,81
SEP	84,21
OCT	104,39
NOV	104,20
DEC	104,87



SPI Values	
2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

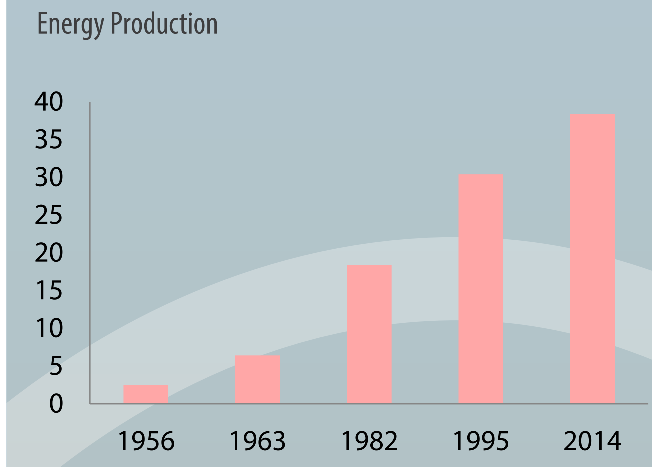


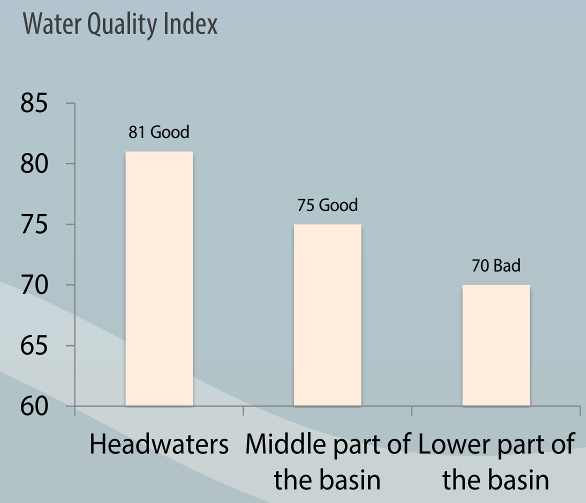
The population growth and the competing water use

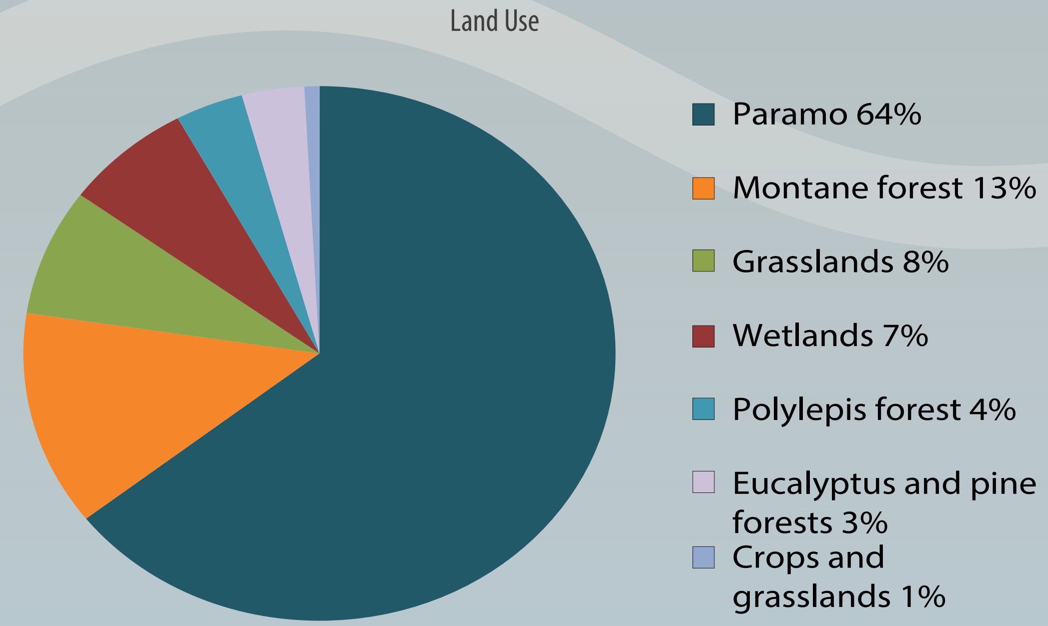
In Ecuador, as in many other developing countries, population growth rates are high. Therefore, the the need for provision of water, food, and energy is increasing. Efforts to meet such demands usually come from isolated initiatives, which generate investment duplication and conflicts in the implementation and operation of specific single-purpose projects. In the Machángara basin, the situation mirrors the national context. The population of Cuenca increased from 330000 inhabitants in 1990 to around 600000 in 2016. Due to the increasing need for water regulation, investments in water storage infrastructure were made in 1972 and 1997 with El Labrado (6 hm3) and Chanlud (16 hm3) reservoirs, respectively. Currently, both reservoirs supply water for 1300 ha of irrigated land, generate 39.5 MW of hydroelectricity, and supply a large part of the drinking-water demand of Cuenca. Food production from seasonal, rain-fed crops, such as potatoes, maize, and beans can be found in the middle part of the basin. On the other hand, hydropower generation in Ecuador increased from 46% (2006) to 90% (2016) as a result of a change in our energy generation policy. This policy has helped to diminish the fossil fuels demand, by investing in renewable energies. In the future, an increased demand for irrigation water, a reduction of natural areas (i.e. in the Machángara water sources) and the intensification of the hydrological cycle are expected; all this will compromise water availability and may create conflicts among users.

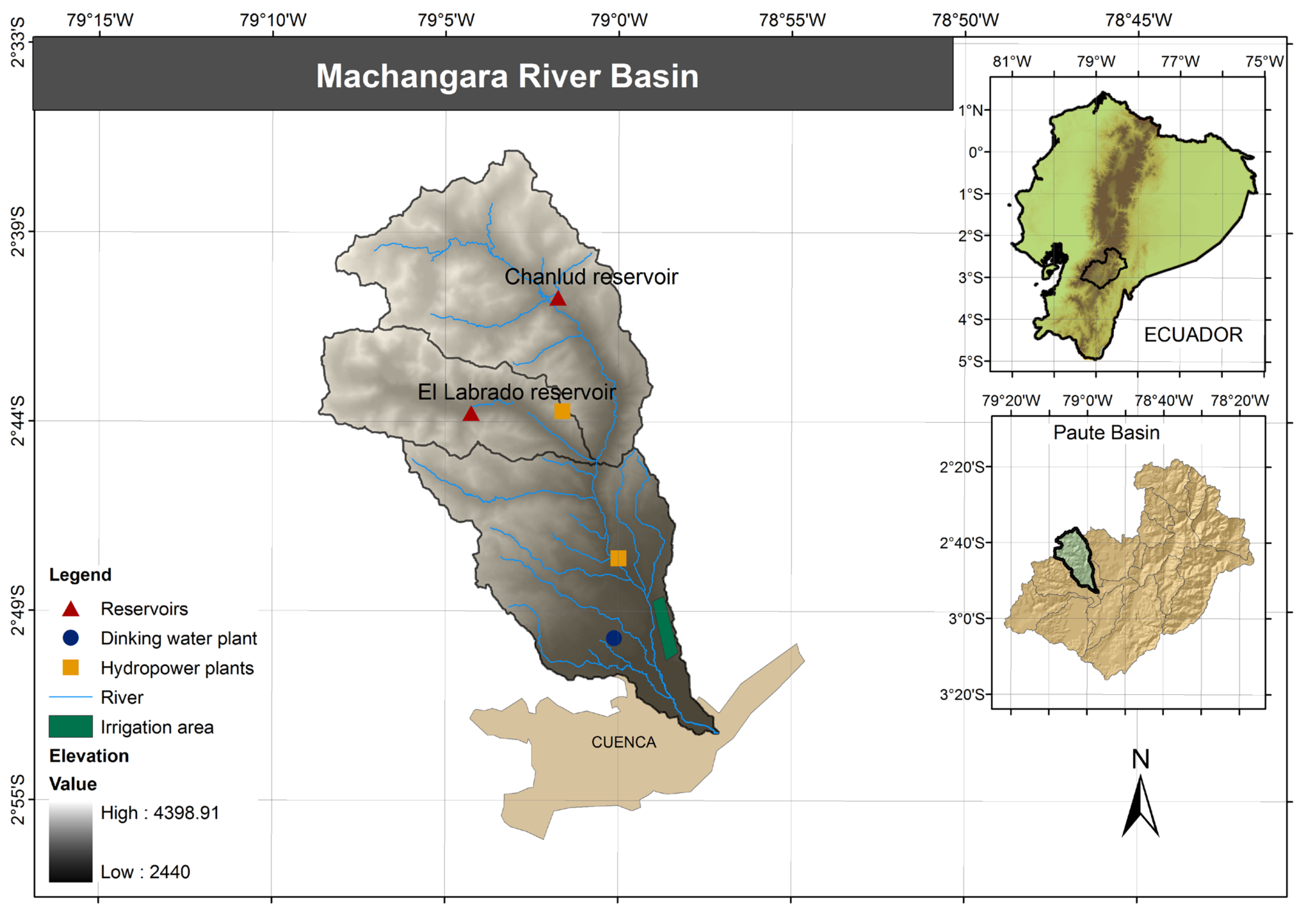
A fast land use change

A study of land use change between 1995 and 2010 shows that in the upper basin 685 ha of Páramo and native forests were replaced by crops and grasslands due to an increased demand of agriculture and livestock production. Below 3000 m a.s.l., the native vegetation has been replaced by crops, pastures and eucalyptus plantations (1300 ha). In the lower part of the basin, the urban area has expanded from 129 ha to 269 ha, reducing the extension of highly productive agricultural areas. Anthropogenic changes have led to a deterioration of natural resources, affecting the normal hydrological functioning of the basin, particularly reducing its flow regulation capacity and its water yield. As a measure to reduce the anthropogenic impacts, in 1985 the Ministry of Environment of Ecuador declared 21000 ha of the basin as a protected area, due to its special, fragile ecosystems and its vital role in the provision of several ecosystem services. However, this has not stopped unsustainable forest use and extraction of firewood, even in riparian areas. In the future, higher competition for land resources is expected, which may lead to a further deteriorating conditions for water availability.









The implementation of the Machángara river basin council

The misuse of natural resources and the competition for limited resources has led to conflicts among users of ecosystem services supplied by river basins countrywide, and the Machángara basin has not been an exeption. For this reason, water-related institutions joined on July 28th, 1998, to form the Machángara River Basin Council. Current members of this council are the Ministery of Environment, ELECAUSTRO S.A. (hydropower company), the Secretaria Nacional del Agua - SENAGUA, ETAPA EP (Cuenca's drinking water company), the General Assembly of Machángara's Irrigation Systems, the Universidad de Cuenca, and the Provincial Government of Azuay. The main objective of this council is to coordinate institutional actions towards sustainable water resources development in the basin. Since its creation, the Council has coordinated and implemented programs for the conservation, recovery and preservation of natural resources in the basin. However, from time to time, there were still duplicated and/or conflicting institutional actions. To help alleviate these problems, in 2012 the Council developed an Integrated River Basin Management Plan in order to improve the management of the basin and coordinate different actions. So far they have initiated some activities proposed in the Management Plan with relative success.

Government of Azuay, by Gernaro Tapia

City of Cuenca, by Marc Figueras

Drought, the main concern for water users

Precipitation in the Machángara River basin presents two rainy seasons (February-May and October-November), whereas the dry months of the year are August-September (Célleri et al., 2007). The cloud frequency varies from around 70% in the dry season to 90% in the rainy season (Campozano et al., 2016). The basin's climate is influenced by the Amazon basin due to the easterlies. While the basin is not particularly prone to flooding, droughts create conflict among water users. Drought preparedness has been oriented to improve short-term drought forecasts (with Markov chain-based methods proving more efficient) and to get better projections of future climate (Avilés et al., 2016). Climate studies show a 2ºC temperature increase for 2030-2050 and an intensification of rainfall seasonality: wetter rainy periods followed by dryer dry seasons. Therefore, expected changes in discharge are an increase of high peak flows and a likely reduction of dry weather flows as a result of longer dry spells. Important gaps in knowledge are the understanding of the meteorological processes occurring in such a complex system – at basin and regional scales – and the effects of climate change on the hydrological regulation of the ecosystems. Beyond the physical system, it is important to understand how the human system will react to water stress situations and how the decision-making process (e.g. for optimizing/distributing water stored in reservoirs) can benefit from models, projections, and decision support systems.

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Events · Projects · Statistics · Agreements

Nexus Timeline: The Machángara River Basin

There have been episodes of conflict among water users in the Manchagara region. During the 1980s and 1990s, when new water projects were developed, there was tension and lack of confidence among institutions. Nevertheless, engineering projects have regulated the natural system and have increased water security. The Machángara River Basin Council has provided the foundations for cooperation, and the Basin management plan will be a great tool to optimize future actions and interventions in the basin. However, changes in land use and climate will most likely put the system under stress in the near future. Therefore, the council may have to shift its role from a coordinating body to a conflict resolution agency in times of water scarcity.

- **1820** – Independence of Cuenca
- **1950** – The Population of Cuenca reaches 122000 inhabitants
- **1956-63** – Construction of the **AYMIRÍN I-II HYDRPOWER PLANTS :** 6.4 MW
- **1972** – Construction of the **EL LABRADO DAM:** (6,5 Hm3) at 3500 m a.s.l.
- **1978-82** – Construction of the **SAUCAY I-II HYDROPOWER PLANTS:** 24 MW
- **1990** – The Population of Cuenca reaches 331000 inhabitants
- **1992-93** – Drought-induced energy crisis forces blackouts in Ecuador
- **1995** – Construction of the **SAYMIRÍN III-IV HYDROPOWER PLANTS:** 8 MW
- **1997** – **THE TIXAN DRINKING WATER TREATMENT PLANT** and **THE CHANLUD DAM** (17 Hm3) start operations
- **2009** – Severe drought cuts off hydropower production and causes US$ 650 million in economic losses in Ecuador
- **2012** – The Machángara River basin management plan is produced
- **2014** – **SAYMIRÍN V** replaces **SAYMIRÍN I-II HYDROPOWER PLANTS** and generates 7.5 MW
- **2014** – Ecuadorian National Assembly approves a new water law, replacing the 1972 water law
- **2016** – The Population of Cuenca reaches 592000 inhabitants

Iguaçu-Falls, by Pixabay

Climate Changes and its Influence on the Brazilian Electricity Sector

Climate changes may induce great impacts on water resources, as floods, droughts and natural disasters have had a strong influence on the history of human society, directly affecting environment, agriculture, industry and the power sector.

Climate issues have had a strong influence on the history of human society, causing great impacts on water resources, through floods, droughts and other natural disasters. Global warming can cause changes in the hydrological cycle through modifications in precipitation and evapotranspiration patterns, which directly affect soil moisture, groundwater reserves and the surface water runoff. These aspects, coupled with an increase in water demand (projected for the coming decades due to population growth and increasing wealth), may exert great pressure on Brazilian water systems (Silveira et al., 2014).

Brazil has a unique energy matrix, basically consisting of hydro-based sources, considered as clean energies. However, it is strongly influenced by the variability of the hydrological inflow regime, whose patterns of variation and uncertainties are to be taken into consideration when planning the operation of the system. This hegemony of hydroelectricity in Brazil requires careful analysis of the river basins and the hydrological variability of flow rates in view of the significant impact that it can produce to national power supply and economy (Alves et al., 2013).

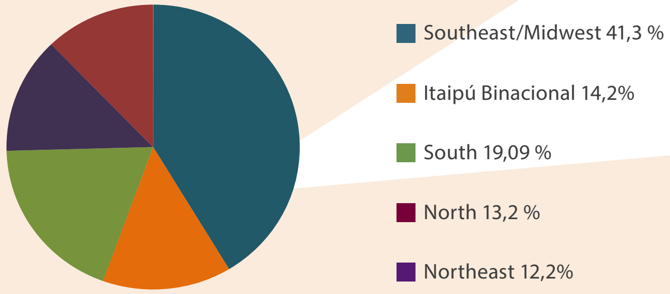
Hydroelectric planning becomes more complex when taking into account the multiple uses of water resources, which must be analyzed from geopolitical, strategic and global points of view, as social and environmental issues and the uncertainty of future climate conditions become increasingly more important (Souza Filho & Silveira, 2015). Therefore, the electricity sector has the responsibility to allocate water in the best rational and optimal way.

"Climate changes, added to the growth of energy demand in Brazil, could lead to a major crisis in the Brazilian energy sector, increasing the cost of power generation and creating a positive feedback to climate changes, intensifying its effects throughout the whole country"

-Assis Souza Filho & Cleiton Silveira

Itaipu Power-plant, by Pixabay

Energy Production per NIPS Subsystem and Itaipu Binacional (2015)



Transmission System (2014)

Tension (kV)	Length (km)
230	52.449,80
345	10.303,20
440	6.728,20
500	40.659,40
600 CC	12.816,00
750	2.683,00
Total NIPS	125.639,60

Hydroelectric Production per River Basin (GWh)

River Basins	2014	2013	2012	2011	2010
Paraná	75.980,00	75.980,00	79.459,50	78.760,60	80.032,50
São Francisco	34.201,00	34.201,00	52.365,20	50.869,10	45.592,40
Tocantins	60.649,00	60.649,00	63.172,50	59.862,50	55.332,50
Iguaçu	37.351,00	37.351,00	30.087,70	41.029,50	38.926,90
Paranaíba	31.733,00	31.733,00	46.014,10	39.423,70	38.041,00
Grande	30.206,00	30.206,00	42.782,80	39.696,80	40.737,10
Uruguai	26.524,00	26.524,00	15.580,10	33.849,50	26.442,90
Paranapanema	15.709,00	15.709,00	13.320,90	12.646,50	14.223,80
Tiete	7.433,00	7.433,00	8.804,60	9.257,00	8.954,30
Paraiba do Sul	7.002,00	7.002,00	6.636,30	6.651,40	7.309,90
Jacui	5.782,00	5.782,00	3.236,10	6.396,30	6.512,30
Other	82.600,40	82.600,40	79.644,20	71.793,70	60.680,50
Total	415.170,40	415.170,40	441.104,10	450.236,50	422.786,10

Brazilian National Interconnected Power System

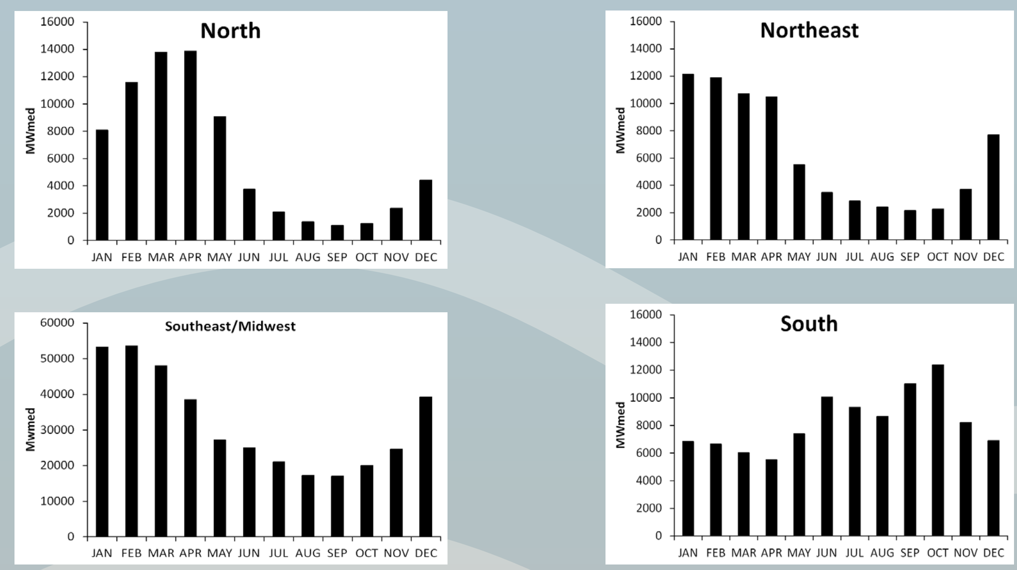
The National Interconnected Power System (NIPS) produces and manages the transmission of electric energy in Brazil, which comes from a large hydrothermal system, predominantly with hydroelectric plants but also with thermal complementation and storage reservoirs. The strategic planning for the long-term water policies occur through "Water Resources Master Plans", comprising a time horizon of some decades. In order to make the most of the energy resources of NIPS and this hydrological seasonality of its river basins, the system is divided into four subsystems: southeast/midwest, south, north and northeast sectors, interconnected by an extensive mesh of transmission lines, which enable the transfer of surplus energy from one region to another and allow the optimization of water stocks in the reservoirs of hydroelectric plants. The Brazilian electricity sector has a great spatial and climatological variability, being influenced by different meteorological phenomena (p.ex., Intertropical Convergence Zone, El Niño – Southern Oscillation) caused by Brazil's continental dimensions. There is a hydrological complementarity between the subsystems that constitute NIPS for the dry and wet periods of its regions do not coincide, resulting in a spatial and temporal coupling of its operation.

At the beginning of every month, the Electric System National Operator (ESNO) carries out the planning of NIPS medium-term operation, defining how much of the total energy demand during that month will be met by thermoelectric plants or by each subset of hydro plants.

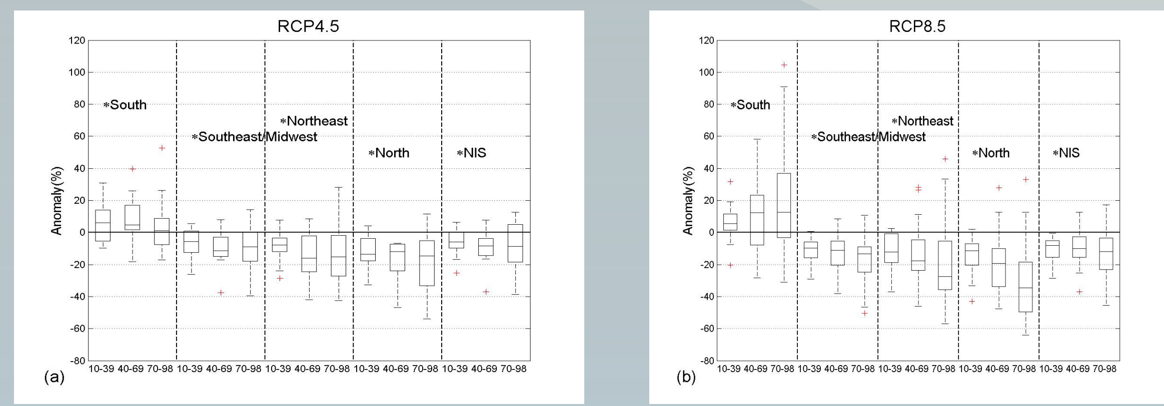
Climate Changes and the Brazilian Electricity Sector

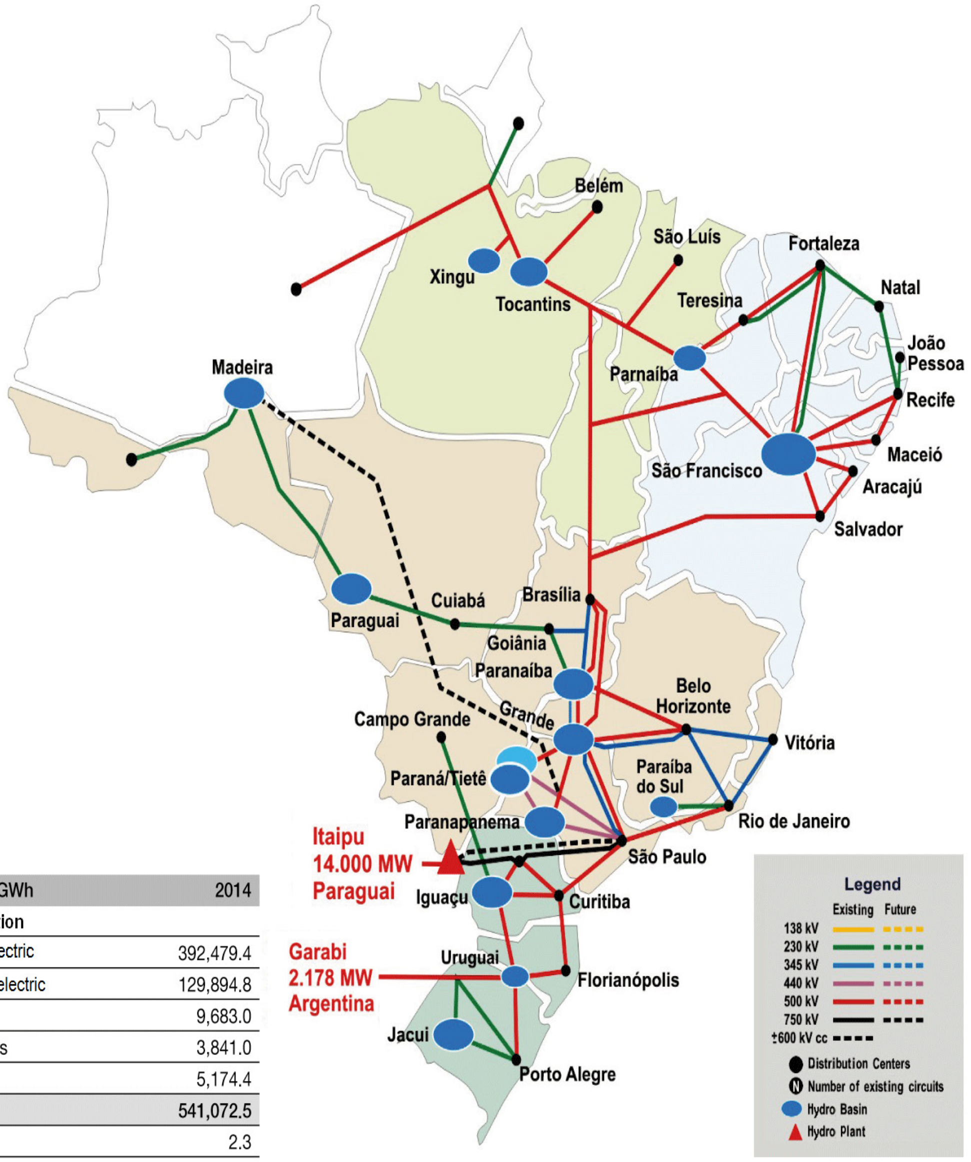
The Brazilian electricity sector river basins present climates with strong temporal and spatial variability of rainfalls, making it vulnerable and eventually leading to major social and economic impacts and making the development of public policies and strategic planning efforts quite relevant. Results of a trend analysis performed by Souza Filho and Silveira (2015), showed an increasing trend (i.e., low frequency variability) in flow rates for the South, Southeast and Midwest regions and a decreasing trend for the North and Northeast sectors. This trend for the North and Northeast regions may result in a reduction of local capacity for the long-term hydroelectricity production. On the other hand, this upward trend in flow rates for the South, Southeast and Midwest sectors can counterbalance this eventual loss, given that most of the hydroelectricity production in the country comes from these three regions. The authors noticed a strong interannual variability and a high range of average flow rates between 1930 and 2010, along with a possible relationship with the Southern Oscillation (El Niño/La Niña) and the Decadal Oscillation Pacific (ODP) anomaly, both linked to climate variability and significantly affecting NIPS stations' flow regimes.

Affluent Natural Energy (ENA), in MWmed, for NIPS subsystems from 2002 to 2011.



ENA annual percentage anomaly for the RCP 4.5 and RCP 8.5 scenarios for the subsystems comprised by SIN.





NIPS - GWh	2014
Production	
Hydroelectric	392,479.4
Thermoelectric	129,894.8
Wind	9,683.0
Biomass	3,841.0
Others	5,174.4
Total	541,072.5
Export	2.3

Brazilian National Interconnected Power System (NIPS)
Credits: ONS (2015).

The authors used IPCC-AR5 models (e.g., BNU-ESM, CanESM2, CSIRO-Mk3-6-0, IPSL-CM5A-MR etc.) for two RCP (Representative Concentration Pathways) scenarios (RCP 8.5 and 4.5) for the periods 1910-1939, 1940-1969 and 1970-1998. Most models showed, for the three periods and both analyzed scenarios, a reduction of the annual Affluent Natural Energy (ANE) in the north, northeast and southeast sectors, and an ANE increase for the south sector. Global models for the RCP 8.5 scenario indicate projections with more intense ANE reductions for the north, northeast and southeast NIPS subsystems, which may be associated with greater temperature increases and a consequent increase in potential evapotranspiration, projected for the 21st century, which directly impacts the naturalized flow rates. Furthermore, the positive anomalies shown regarding the south subsystem are more intense for scenario RCP 8.5 than for RCP 4.5, indicating the possibility of years with more intense rains and higher surface runoffs. Analyzing the models with significant trends when all NIPS sectors are considered, there is clear evidence that the increase in emissions of greenhouse gases suggests a greater impact on the Brazilian electricity sector power generation. The Intergovernmental Panel on Climate Change (IPCC) points out that climate changes will impose a worldwide threat to social and economic development during the 21st century, largely affecting a big part of the population, water resources, urban and rural infrastructures, coastal zones, forests and biodiversity, as well as economic sectors like agriculture, fishing, industry and power generation, which includes the hydropower sector (IPCC, 2014).

At the beginning of every month, the Electric System National Operator (ESNO) carries out the planning of NIPS medium-term operation, defining how much of the total energy demand during that month will be met by thermoelectric plants or by each subset of hydro plants.

Iguaçu Falls, by Pixabay

Wind Farm in Ceará, by Newton Montezuma

Sunset in Brazilian Northeast region, by Pixabay

The most recent models regarding climate prediction for Brazil suggest the need for increased investment in water infrastructure, a greater share of energy coming from power thermoelectric plants in the national energy matrix, and/or increased investments in renewable energy sources (wind, photovoltaic, biomass) so that the reduction in the supply will not impact the power generation and the 20th century's service coverage level can be maintained in the 21st century. The investment in large water infrastructure, however, can lead to serious environmental damages, especially if it is intended for the north region (Amazon). If current consumption patterns are maintained (i.e., greater consumption than production in the south and southeast regions of Brazil, and also an increased possibility of generation in the north sector), it may be that the costs of energy for some consumers will increase, due to the high costs related to energy transmission between regions. Climate changes, added to the growth of energy demand in Brazil, could lead to a major crisis in the Brazilian energy sector and result in investments in non-renewable sources, due to the risk of not ensuring an adequate response to users' demands. This type of action may increase the cost of power generation and create a positive feedback to climate changes, intensifying its effects throughout the country. Another possibility in anticipation of the projected climate change is a massive investment in renewable resources, so that they achieve greater participation in the Brazilian energy matrix. However, this requires a complex policy of investments in technology and manpower training aiming to reduce long-term costs.

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Events | Projects | Statistics | Agreements

Nexus Timeline: Brazilian Electricity Sector

With about 8.5 million square kilometers of area and more than 7,000 kilometers of highly favorable coastal and climate conditions, Brazil has one of the world's biggest and best energy potentials. Electricity has always played a fundamental role in Brazil's development. Starting its activities in the country during the 19th century, the power sector, along with national economy, has gone through several periods of growth and crisis. In this context, the Brazilian energy matrix has been framed along the years, since the first steps of the electrical industry in the country until the contemporary status quo of the sector, which has gone through substantial reformation and restructuring, as well as the danger of an energy collapse (1995-2002) due to a lack of production in a period of great industrialization and economic growth. If the fossil fuels reserves are relatively low in Brazil the potential for hydro, photovoltaic, biomass and wind power are sufficiently abundant to practically ensure energy self-sufficiency. However, the country still needs an electricity system that is compatible with its dynamics and dimensions.

1920
- (Agreements) The industrialization of the economy led to a growth in the number of hydro plants
- (Statistics) The Brazilian Population reaches 30.6 Million

1934
- (Events) Brazilian Government enacts the **NATIONAL CODE OF WATERS**

1957
- (Events) Inauguration of **FURNAS HYDRO PLANT** to supply the Southeast region

1961
- (Events) Inauguration of **VALE DO PARAÍBA HYDRO PLANT**

1970
- (Agreements) A period with strong influence of the state on the electricity sector
- (Statistics) The Brazilian Population reaches 94.5 Million

1984
- (Projects) Inauguration of the **HYDROELECTRIC PLANT ITAIPU BINACIONAL**, world leader in clean, renewable energy

1985
- (Agreements) Government creates the **NATIONAL PROGRAM FOR ENERGY CONSERVATION (PROCEL)** to promote rationalization in production and consumption, eliminate waste and losses and reduce costs

1988
- (Agreements) Creation of the **ELECTRIC SECTOR NATIONAL OPERATOR (ESNO)**
- (Statistics) Evolution of Brazil's electricity production capacity (MW/year):
  - 1952: 2,806
  - 1962: 5,729
  - 1972: 13,249
  - 1982: 38,989
  - 1992: 54,141
  - 2003: 86,179
  - 2014: 133,900

1997
- (Agreements) Officialization of the **NATIONAL POLICY FOR WATER RESOURCES** in Brazil

2000
- (Statistics) The Brazilian Population reaches 169.5 Million
- (Agreements) Governmental Incentives for the development of Wind and Photovoltaic Power Plants

2001/02
- (Events) Period of strict rationing of electricity in Brazil

2003
- (Agreements) The National Program **LUZ PARA TODOS**, was launched, aiming to supply every home with eletricity

2005
- (Statistics) Cost of MWh in the electricity auction: USD 43
- (Events) 1st Electricity Auction in Brazil: "reverse auctions" to trade electricity-related products

2007
- (Events) 1st Electricity Auction dedicated to renewable sources
- (Statistics) Cost of MWh in the auction: USD 58

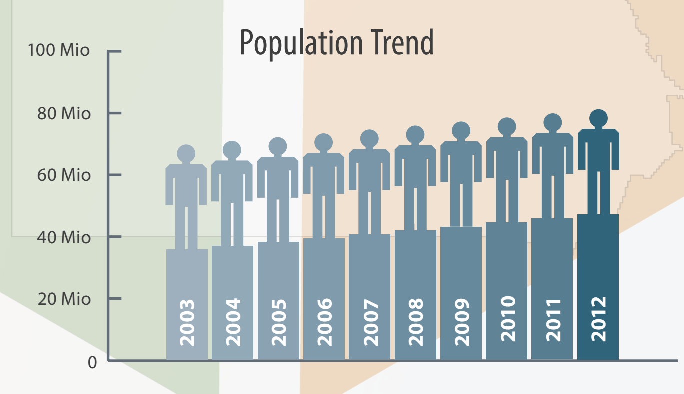
2014-15
- (Events) Period of strong droughts in the southeast region of Brazil and water rationing
- (Statistics) The Brazilian Population surpasses 212 Million

Nexus Profiles

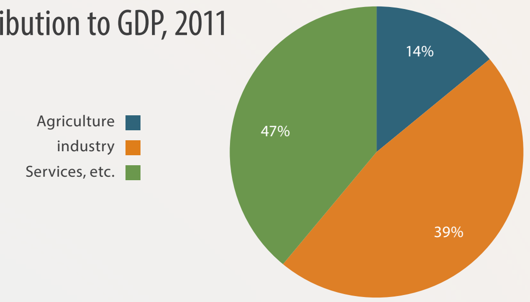
Nexus
Water | Energy | Food Security

Egypt

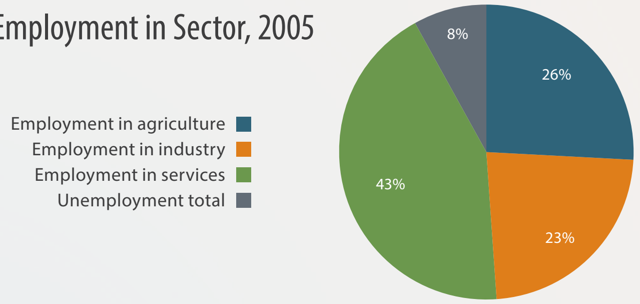
Nexus Country Profile



Sector Contribution to GDP, 2011



Employment in Sector, 2005



Investment and Sector Finance

General government final consumption expenditure (constant 2005 US$/% of GDP): 14,236 mio./11 (2012) [1]
Household final consumption expenditure/per capita (constant 2005 US$): 96,436 mio./1,176 (2012) [1]
Foreign direct investment net inflows, (bio. current US$/% of GDP): 2,8/ 1.1 (2012) [1]
Net ODA received (% of central government expense): 0.6 (2011) [1]
Agriculture (source denotes incomplete data)
[7] Total investment in agriculture sector and related industrial sub-sectors (mio. US$): 12,021 (2008)
Share of government investment (%): 69.4 (2008)
Share of foreign investment (%): 30.6 (2008)
Total land area allocated by foreign investment: 10,000 ha by Saudi Arabia agricultural firms [4,5]*

Water [12, 14, 9]
Egyptian government budget on water infrastructure (bio. US$): 663 (2004)
Egyptian government budget on water supply and sanitation (bio. US$): 1,086 (2004)
Private/foreign investment in water sector: no data available
Low recovery levels in water sector - tariff financial flow accounts for 10% (2009)

Energy
Governmental expenditure in energy sector: no data available
Private/foreign investment in energy sector: no data available
Subsidies in food and fuel account for the largest part in government spending with 18 mio. $ in 2011 to 2012 [10]

Country Data

Total land area (ha): 99,545,000 [3]
Population density (people per km^2 of land area): 80 (2011) [1]
Population growth (%): 1.7 (2012) [1]

GNI per capita (2005 PPP $): 5,704 (2012) [2]
GINI coefficient: 30.8 (2011) [1]
Poverty gap at national poverty line at 1.25$ (PPP) (%): 4 (2005) [1]
HDI value: 0.662 (2012) [2]
MPI value: 0.024 (2008) [2]
GII value: 0.59 (2012)[2]

Mean years of schooling (a): 6.4 (2012) [2]
Adult literacy rate, ages 15 and above (%): 74 (2012) [1]

Life Expectancy at birth (total years): 71 (2011) [1]
Mortality rate under 5 (per 1000 of live births): 21 (2012) [1]

GDP and WEF Sector

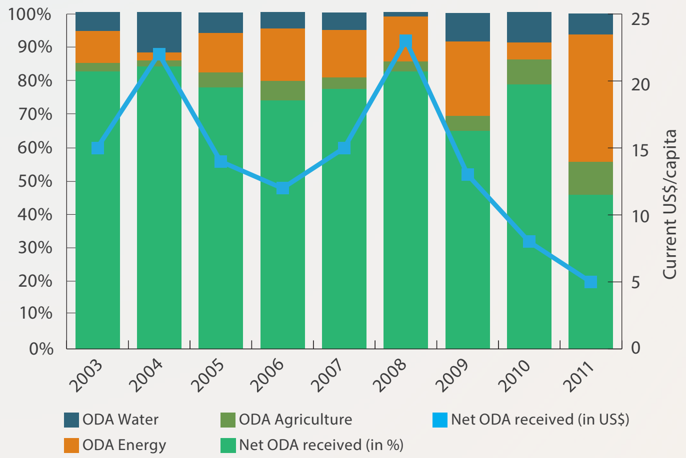
GDP per capita (constant 2005 US$): 1560 (2012) [1]
GDP growth annual (%): 2.2 (2014) [1]

Government revenues (bio. US$): 302,009 (2011) [13]
Government spending (bio. US$): 436,148 (2011) [13]
Central government debt, total (% of GDP): 86 (2007) [1]
Inflation, GDP deflator (annual %): 12 (2012) [1]

Tax revenue (% of GDP): 14 (2011) [1]
Subsidies and other transfers (% of expense): 42 (2011) [1]

GDP by sector, electricity and water (%): 1.9 (2006/2007) [11]
GDP by sector, industry, petroleum & mining (%): 32.4 (2006/07) [11]

Official Development Aid in Sectors



Nexus Country Profile Water

Water available per capita: 682.5 m^3/cap*a (2011) [1]
Water consumption per capita: 973.3 m^3/cap*a (only 2000) [1]

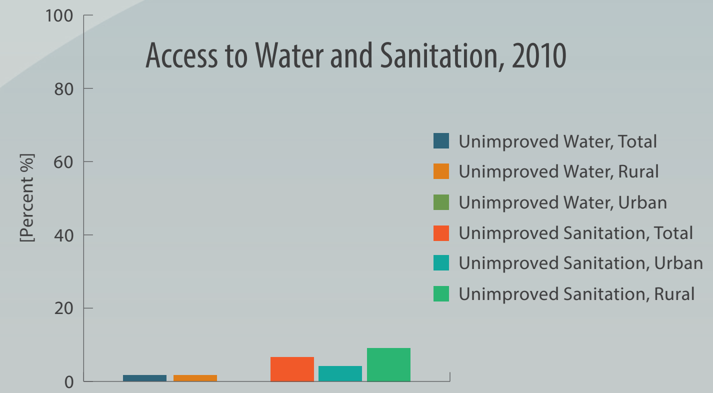
Rainfall average: 51mm/a [2]
Rainfall distribution spatial: 0-200mm/a [2]
Rainfall distribution temporal: low, irregular & unpredictable [2]

Internal Renewable Water Resources
Surface Water, actual: 56km^3/a (99% Nile, 2011) [1]
Groundwater, acutal: 1.3 km^3 (2011) [1]
Total renewable resources, acutal: 57.3 km^3/a (2011) [1]

Direct use of agricultural drainage water: 11 km^3/a (2001)[1]
Produced/collected/treated municipal wastewater: 8.5, 6.5, 4.8 km^3/a (2011) [1]
Direct use of municipal wastewater/for irrigation: 0.7/0.29 km^3/a (2011) [1]
Desalination water: 0.1km^3/a at north coast (2002) [1]
Non renewable sources, estimated: 0.6 to 3.8 km^3/a [2]

Balances:
Surface water entering the country, natural: 84 km^3/a (2011) [1]
Surface water leaving the country, natural: 0km^3/a (2011) [1]
Surface water inflow secured/submitted through treaties: 55.5 km^3/a (2011) [1]

Access to Water and Sanitation, 2010



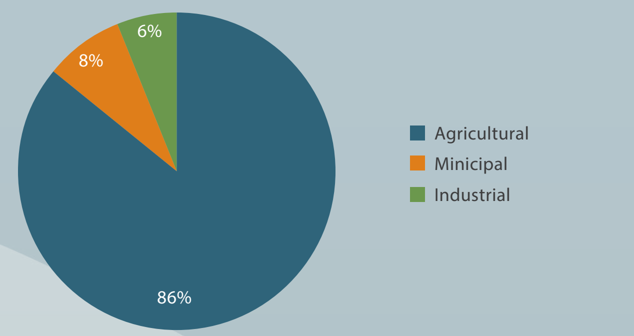
- Rapidly decreasing water resources per capita due to population growth and contamination
- Very high dependency on Nile water resources with growing vulnerability to changes in water use of upstream countries
- Despite high access to improved water sources, several protest movements in the last years are due to disruptions in supply, water quality and pricing [3]
- 47% of rural population has no access to sewer systems, resulting in correlated contamination of groundwater bodies due to low water levels [4],[7]
- 6.5 km^3 of 8.5 km^3 generated wastewater is collected, but only 4.8 km^3 is treated [1]

Water for Energy

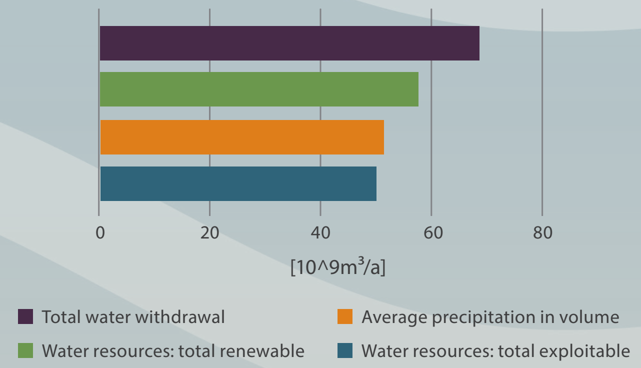
Hydropower
Hydropower is the third largest source for electricity in Egypt and accounts for 8% (2011) of electricity generation [8]. Hydropower generated 12.93 TWh in 2011[9]. The installed capacity of 2,692 MW is often not exploited due to low water levels [10]. The existing two dams and reservoirs, the Aswan Dam and the low Aswan Dam, have a storage capacity of 162 and 5 km^3[11]. FAO indicates that the overall use for hydropower accounts for 4km^3 annually [2].

Biofuels
Wastewater is being reused in Egypt for biofuel production with active governmental promotion. In total, 0.26 bio. m^3 of secondary treated wastewater and 0.44 bio. m^3 of primary treated wastewater are reused for irrigation [16]. According to Abdel Shafy, the extensive use of sewage water for irrigation affects groundwater resources. His study revealed that the majority of water samples exceeded the maximum levels for BOD, COD and faecals.

Water Withdrawal by Sector, 2004



Water Resources and Consumption, 2011

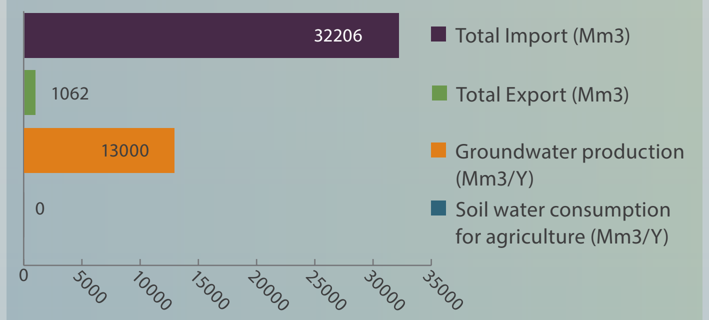


Water for Land/Food

Water Efficiency and Cropping Patterns
On the cultivated area in Egypt, 94% are annual crops, and 6% are permanent crops. There is a decrease in cultivation of fibre, oil, fodder and legume crops and a correlated increase in cereals, fruit, sugar and vegetables. The three cropping seasons are the summer, winter and Nile season. Only 0.2% of croplands are rainfed, the remaining area is irrigated. Surface irrigation accounts for 302,854 ha; 171,910 ha for sprinkler and 221,415 ha for drip or trickle irrigation [5].

Virtual Water
[6] Major crops imported and associated with virtual water are soybeans, followed by wheat and maize. Major exported crops associated with virtual water are citrus and sugar.

Virtual Water, 2006



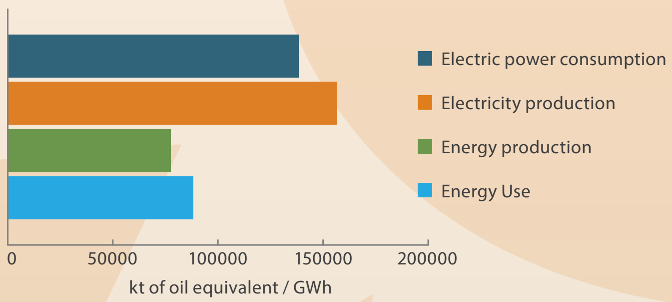
Pollution
The main pollution source in Egypt is industry, due to direct or after treatment discharge of sewage. Although drainage water in the delta region is reused, it is directly discharged in the upstream region. Increasing use of fertilizers and pesticides caused flourishing of weed and, therefore, an increase in evapotranspiration. Also, there are high levels of pollutants because of uncontrolled and accumulated discharge[7].

Nexus Country Profile Energy

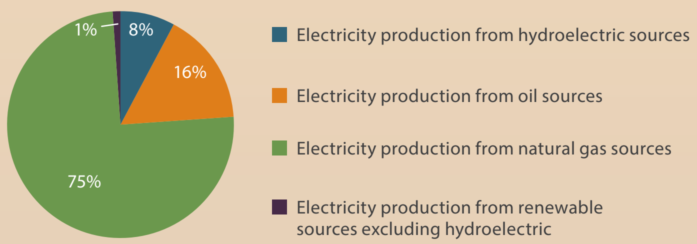
Energy use per capita: 987 ktoe/cap*a (2011) [1]
Electric power consumption per capita: 1743 kWh/cap*a (2011) [1]
TPES: 77.69 Mtoe (2011) [2]

Reserves and Potential:
Crude oil reserves: 4,400 mio. barrels (2013) [3]
Natural gas: 2,186 trillion m³ (2013) [3]
Coal reserves: 17 mio. short t (2008) [4]
Solar potential, DNI: 74 bio. MWh, 1970 to 3200 kWh/m²/a [5]
Biomass potential: 40 mio. tons, 3,600 ktoe [5]
Wind potential, wind speed: 20,000 MW, > 7m/s in Western part [5]
Geothermal potential: no data available
Falling water, total hydraulic resources: 125,000 mio. kWh (2008) [6]

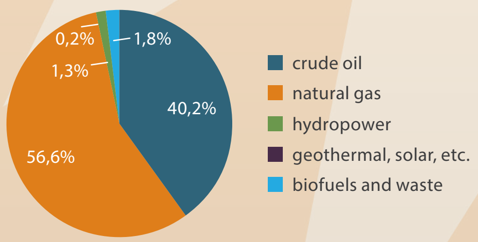
Energy Production and Consumption, 2011



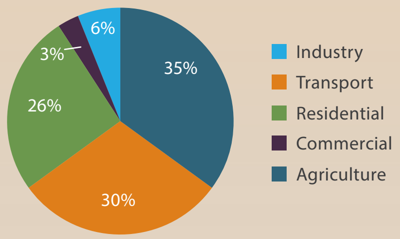
Electricity Production, 2011



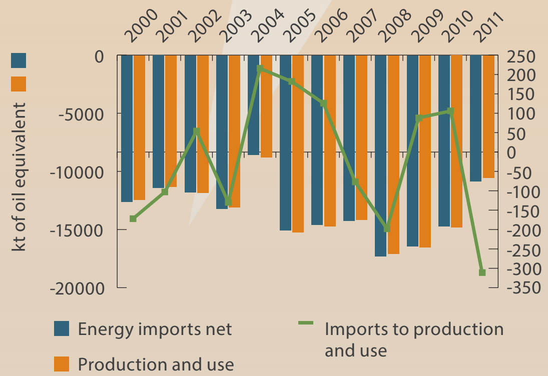
Energy Production Sources, 2011



Energy Use by Sector, 2011



Energy Imports Exports Balance



Egypt is the largest energy consuming country in North Africa. Energy consumption per capita is in the upper middle range. Highest energy consumption is in Industry (35%), Transport (30%) and Residential (26%) [2]. Energy exports in 2011 (22,258 ktoe) exceeded imports (12,704 ktoe) [2]. Access to electricity is 100%. [1] Emissions in 2010 were around 205 Mt of CO2 (2.6 metric tons per capita). Methane emissions in the energy sector account for 29,711 metric tons of CO2 equivalent in 2010.

Energy for Water

Energy consumption for water is generally high in Egypt because water supply is dependent on pumping water from the Nile to higher levels. Egypt has more than 560 pumping stations with more than 1,600 single pumping units for irrigation of cultivated land. The amount of electricity needed to operate these stations is indicated in 930 GWh [10].

Desalination

Due to increasing water scarcity and demand, many desalination plants have been built in the last 30 years. In 2002, the amount of desalinated water was 100 mio. m³[11]. Water desalination leads to increasing energy consumption. According to estimations by Garcia Rodrigez (2003), 13 mio. m³ of water require 130 mil tons of oil, which furthermore could drastically increase the energy demand and CO2 emissions [11]. Although energy use for pumping and potable water production seems to be quite high, Egypt was reported to be one of the countries with the least energy intensity in water supply [13].

Energy for Land/Food

Energy Use in Agriculture

The energy use in agriculture in Egypt has experienced a high increase over the last year but remains small in general – around 60% of total energy consumption in Egypt in 2010[2]. The total energy consumption in 2000 was 292 ktoe with 75% accounting for electricity. In 2010, it increased to 3,685 ktoe. Energy use in agriculture is expected to rise due to increasing scarcity and production. When comparing the data reported by IEA, the highest electricity consumption in agriculture was recorded in 2010 with 494 GWh and does not nearly reach the required supply for pumping, as reported by Khaled. Further data on the specific use patterns are not available.

Machinization

Since the late 1970s, agricultural machinery shows a steady increase - 103,188 tractors in use in 2008 [7]. In 2000, the area under power irrigation was 29,379 km³ [8]. While irrigation systems in the old land of the Nile Valley are based on combined gravity and water lifting systems, the supply in the new lands is dependent on pumping stations [9]. In the new lands, there is no legal permission for surface irrigation, thus irrigation is based on sprinkler and drip technologies. Modernization efforts towards efficient use of water in the agriculture sector might lead to an increase in energy consumption.

Nexus Country Profile Land

Agricultural land per capita: 0.046 ha/inh. (2009) (knoma)
Cultivated land per capita: 0.045 ha/inh. (2011) (knoma)
Food production per capita, Gross PIN: 107 (2012) [13]

Agriculture to GDP: 14% (2011) [1]
Employment in agriculture: 24% (2011) [1]

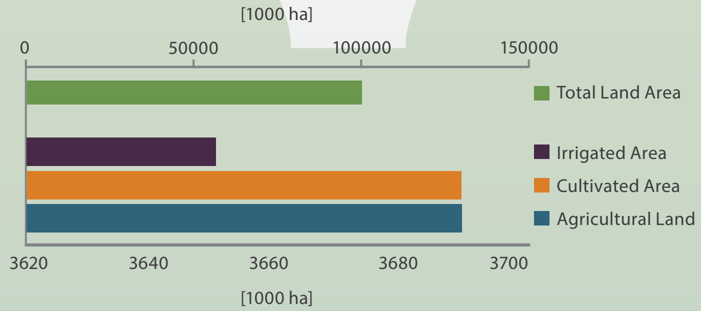
Prevalence of undernutrition: -5% (2010-12)[5]
Share of food consumption expenditure: 45% (2009)[3]
Food supply per capita: 3477 kcal/capita/day (2009) [5]

Production Systems: 90% farm sizes within scale of 2 acres
tendency to new land ownership > 5 acres
small proportion in mega projects of 3-4 mio. acres [4]

Main production commodities, quantity: sugar cane & beet, wheat (2011) [5]
Main export product:, value: oranges, cotton, sugar (2011) [5]
Main import product, value: wheat, maize, sugar (2011) [5]

Production Index

Land use



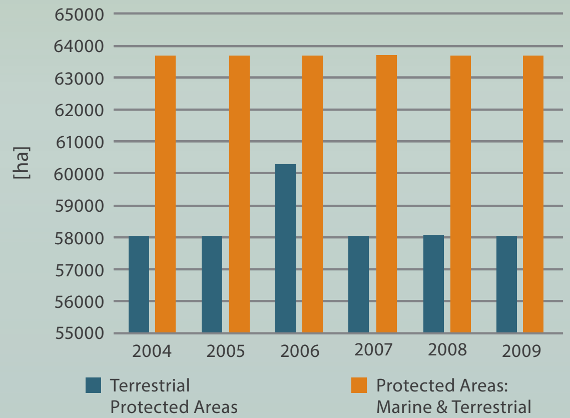
Food Imports and Exports in Egypt

- 96% of land area in Egypt is desert
- Agricultural activities and population located along the Nile Valley
- Extreme water stress and increasing vulnerability to climate change [9]
- Highly dependent on food imports [1], [9]
- Trend of decreasing aid deliveries, despite acceleration of food insecurity due to increasing poverty rates and other economic crises

Land for Water

Protected Areas
The proportion of protected areas is stagnant at 6.08% [6]. The majority of these are terrestrial protected areas with 580km² of 638km². Water pollution is one of the key concerns for protected areas. In rural Egypt, wastewater treatment is not included in governmental plans [7]. With a growing population, substantial investments need to be made to protect these areas from further pollution.

Terrestrial and Marine Protected Areas

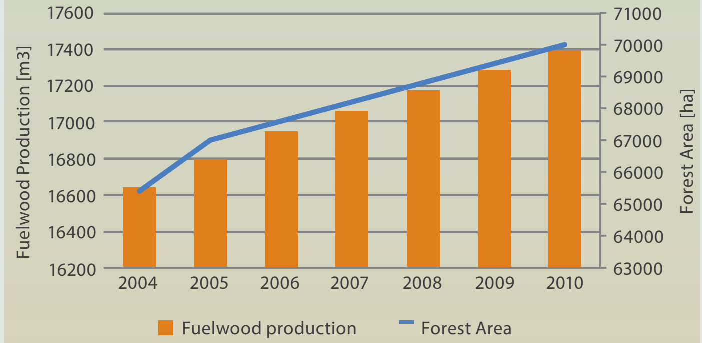


Reservoirs
The resource potential for dams in Egypt is almost exploited [8]. Lake Nasser is the biggest reservoir in the country and covers a surface area of 5,250 km². The lake resulted from the construction of the Aswan High dam in the 1950s, which supplies Egypt with much of its energy.
Since rainfall is very scarce in Egypt - annual averaged precipitation amounts in 12mm, rainwater harvesting could only be implemented at the coastal zone [10]. A pilot plant for harvesting was constructed in Alexandria and revealed that it can be a significant option for Egypt considering increasing resource scarcity.

Land/Food for Energy

Land for Fuelwood
Biofuels in Egypt are mainly fueldwood. Since 1994, the government has implemented reforestation plans with a focus on treated wastewater as a irrigation source for plantations in cities and on production of fuelwood [11]. The forest area increased slightly to 70,000 ha in 2010[1]. Fuelwood production from nonconifereous wood was 17,397 mio. m³ in the year 2011 [1].

Forest Area and Fuel Wood Production



Land for Biofuels
According to IEA, energy production by biofuels and waste was 1,617 ktoe, of which 24 ktoe were exported in 2011. Recently, national programs for the use of wastewater for afforestation planted 84 ha of jatropha for biodiesel production [12]. Limitations exist regarding the stages of treatment, the crop type and the purpose of usage. According to Said (2013), the theoretical energy potential of residues is huge with 417 PJ mostly generated in agriculture and consumed in rural areas..

Egypt
Rapid Assessment

Nexus
Water | Energy | Food Security

Overall Assessment

NEXUS CHALLENGES

Egypt faces major water, food and energy security challenges which are magnified by the political instability and severely decreasing economic growth since the 2011 revolution.

The Nile is Egypt's only renewable water source; however, the shifting geostrategic balance between states in the Nile basin means it threatens Egypt's share of the Nile's flow. Pressures on water resources have increased with population growth, and the per capita share of water has decreased.

In regards to energy, Egypt is heavily dependent on its oil and gas reserves. The energy demand is likely to grow due to increasing energy consumption in the agriculture and water sector, and the growing population and economy.

One in five Egyptians are currently experiencing food insecurity as a result of structural issues in the food supply system. There is a growing gap between Egypt's long-term agricultural production potential and its estimated population growth. The country is dependent on the global food market to secure the food demand of its population, but a reduction in imports appears difficult to obtain, given land availability and production yield.

Water shortages will have a severe impact on Egypt's food security. Of Egypt's total water supply, 80% is used for agriculture. As water availability shrinks and available agricultural land is used, Egypt's food production capacity will fall. The impacts of resource scarcity will be exacerbated by the changing global climate.

In the longer term, environmental issues related to solid waste management, air pollution, small holder farming combined with land degradation and the loss of biodiversity are intensified by an increasing population and limited by arable land, desertification and climate change. These pose significant challenges for food security.

SOLUTIONS

To address the present challenges, Egypt has to resolve the structural weaknesses of the economic sector and attract private investment to return sustainable economic growth.

In terms of water security, Egypt could protect areas from further pollution in addition to improving the sanitation value chain in order to assure safe transportation and treatment of excreta. Part of the capital needed for the interventions could be gained through a more effective water tariff system. Despite the affordability of water and sewer tariffs, which are amongst the lowest in the world, only a fraction of costs is recovered through revenues from tariffs. To achieve this, the government will need to cooperate with regional stakeholders on water allocations.

Egypt currently has underutilised potential for renewable energy resources; these could be implemented to satisfy increasing energy demands. However, in the future Egypt will need to consider the importation of energy produced by the Grand Ethiopian Renaissance Dam.

Considering the increasing population, Egypt will not be self-sufficient in terms of food security. The country needs to increase food imports without exacerbating the structural fiscal deficit. Trade based food security may not be viable in the long-term if Egypt is unable to amend its struggling economy. Therefore, the country has to explore major gains that can be achieved in the efficient use of agricultural inputs and reduction of waste throughout the food system, including restructuring the food subsidy system. A comprehensive effort is required to improve agricultural productivity and reduce losses throughout the food and water supply chains.

Water Security

Egypt is reliant for 98% of its water supply from the river Nile with a growing vulnerability to the changing water uses of upstream countries. Water insecurity rises due to population growth and contamination. Despite high access to improved water sources, several protest movements have occurred in the last years due to disruptions in supply, water quality and pricing.

Water supply ●●●○○
High access to improved water sources, low access to improved sanitation, and weaknesses along the sanitation value chain in safe treatment and disposal of excreta.

Virtual water ●●●○○
Virtual water embedded in food import is increasing. Major exported crops associated with virtual water are citrus and sugar.

Protected Areas ●●○○○
Missing monitoring programs and environmental regulations on protection of water bodies cause a high threat to nature and the population.

Reservoir ●●○○○
High loss in storage capacities of reservoirs due to increasing sedimentation.

Pollution ●○○○○
High discharge of untreated excreta into water bodies, pollution of groundwater and high concentrations of DDT in potable water storages due to the use of pesticides in agriculture.

Energy Security

Egypt is the largest energy consuming country in North Africa. Energy security is endangered because of the rising energy demand in the water and agriculture sectors.

Biofuels ○○○○○
Wastewater is being reused in Egypt for biofuel production with active governmental promotion.

Land for Biofuels ○○○○○
Recently, national programs for biodiesel production have been implemented.

Fuelwood ●●○○○
Biofuels in Egypt are mainly fuelwoods. This can negatively affect soil quantity.

Wastewater for Energy ●●●○○
There are existing reforestation plans with focus on treated wastewater as an irrigation source for plantations.

Hydropower ●●●○○
Hydropower is the largest source of renewable energy. Yet, its contribution to total energy consumption is small.

Fossil fuels ●●●○○
The main energy source is fossil fuels. Oil and gas reserves are the main energy suppliers.

Access to Electricity ●●●●○
The entire population has full access to electricity. Energy cuts and shortages have been a problem recently.

Food Security

The prevalence of combined food insecurity and income poverty in Egypt is increasing . Population growth and urbanisation are encroaching onto strips of fertile land adjacent to the Nile. The consequent environmental degradation is leading to contamination and desertification of the limited remaining fertile areas. Efforts to reclaim land from the desert in order to counteract this trend are restricted by the need to secure sufficient water supplies. Therefore, Egypt relies on the global market for up to 60% of its food needs, which has been a major cause in the rise of Egypt's food insecurity in the past.

Cropping patterns ●●●●○
The three cropping seasons are the summer, winter and Nile season. Only 3.5% of Egypt's landmass is potentially arable. The remaining land is arid desert.

Energy use in Agriculture ●●○○○
Energy use in agriculture is expected to rise due to increasing scarcity and production but remains small in general.

Water use efficiency ●●○○○
Croplands are largely dependent on irrigation, of which surface irrigation is the most common technique. Water use efficiency is below international standards.

Food markets ●●●○○
Dependency on food imports increase, whereas self-sufficiency declines. Local food markets exist and are functioning.

Productivity in Agriculture ●●●○○
Urbanisation and environmental degradation endanger Egypt's already limited fertile areas. The total area of land cultivated has decreased.

Rating

The rapid assessment of the situation above, based on available data, was established following the UN Water Country Profiles. It provides an overview of trends according to the following:

○○○○○ *insufficient data*
●○○○○ *trends are of significant concern*
●●○○○ *trends are of concern*
●●●○○ *trends are stable or progressing on certain issues but not on others*
●●●●○ *trends show some measure of improvement in all relevant indicators assessed*
●●●●● *trends show significant improvement and there is no concern*

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Egypt

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Useful Resources:

Data Sources:

World Bank Country Database
IEA Statistics
FAO Country Profiles Database
FAO Aquastat Database

Nexus Websites:

www.water-energy-food.org
www.thenexusnetwork.org
www.gracelinks.org
www.futureearth.org

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Ethiopia

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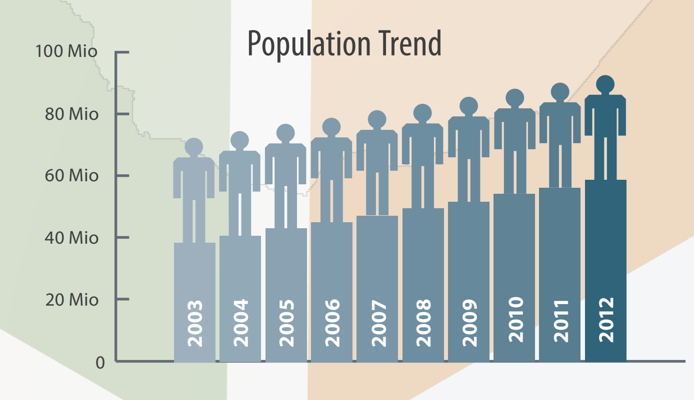
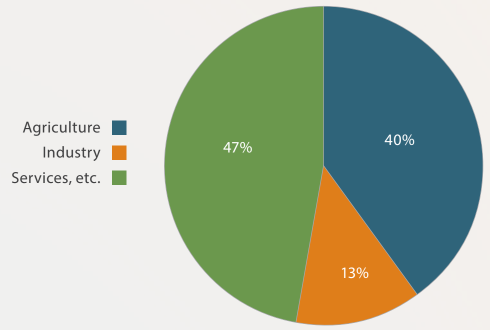
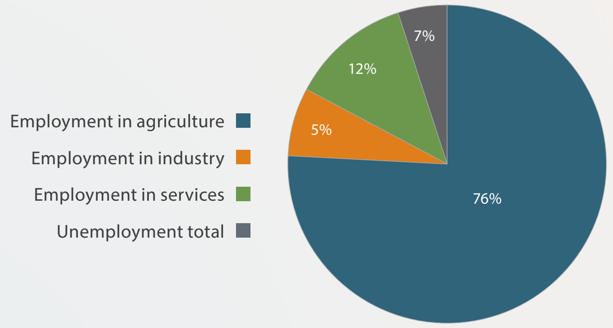
Population Trend



Sector Contribution to GDP, 2011



Employment in Sector, 2005



Country Data

Total land area: 100,000,000 ha [3]
Population density, people per km² of land area: 89 (2011) [1]
Population growth: 3% (2012) [1]

GNI per capita, 2005 PPP $: 1.017 (2012) [2]
GINI coefficient: 29.8 (2011) [1]
Poverty gap at national poverty line, at 1.25$ (PPP), %: 8, 8 (2011) [1]
HDI value: 0.396 (2012) [2]
MPI value: 0.564 (2011) [2]
GII value: data not available [2]

Mean years of schooling: 8.7 (2012) [2]
Literacy rate adult total, 15 and above: 39 (2007) [1]

Life Expectancy at birth, total years: 62 (2011) [1]
Mortality rate under 5, per 1000 of live births: 68 (2012) [1]

Investment and Sector Finance

Total land area allocated >500 ha,
local/foreign investment (ha):
1.2 mio./602,760 (2009)

Total investment in agriculture (mio. US$):
17.9 (2009/2010) [8,9]

Foreign investment in agriculutre and mining (mio. US$):
28.1 (2004)
Mainly private sector to government investment,
land in Ethiopia is state owned [5,7]

Water
Government expenditure in water sector
(% of total expenditure): 8.2 (2010/2011) [10]

Energy
(Sector Water, Mining & Energy Resource Dev Bureau)
budgetary allocations (% of total expenditures):
1.85 (2001)[11]

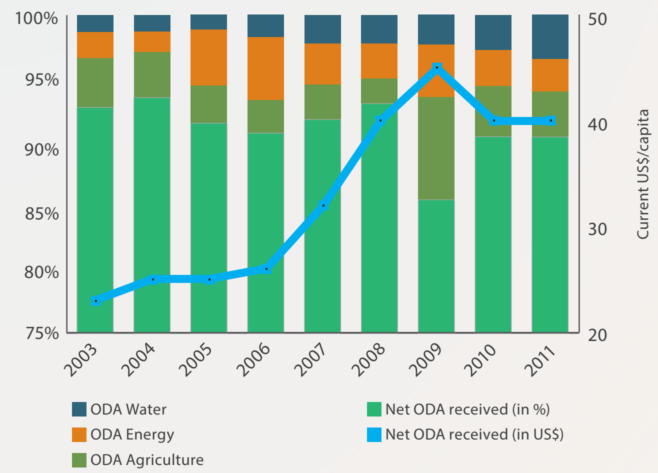
GDP and WEF Sector

GDP per capita, constant 2005$: 256 (2012) [1]
GDP growth annual: 10.3% (2014) [1]
Unemployment total, of total labour force: 17% (2006) [1]

Consumption and Foreign Inflows

General government final consumption expenditure, constant 2005 US$:
1,633 mio.
Household final consumption expenditure, constant 2005 US$: 17,769 mio.
Foreign direct investment net inlows, (mio. US$/% of GDP): 970/0.7 (2012) [1]
Net ODA received, % of central government expense: 104 (2014) [1]
Agriculture (denote incomplete data) [4,5]

Official Development Aid in Sectors



Nexus Country Profile Water

Water available per capita: 1.410 m³/a (2011) [1]
Water consumption per capita: 80.5 m³/a (2002) [1]

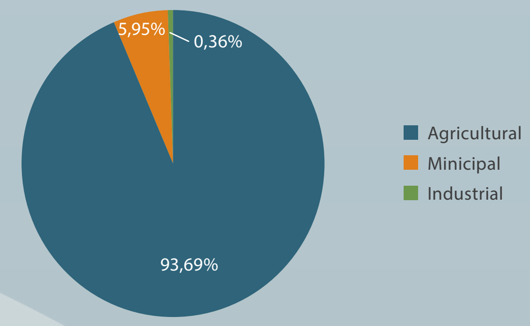
Rainfall average: 848 mm/a [2]
Rainfall distribution spatial: 100-2000 mm/a [2]
Rainfall distribution temporal: highly erratic, extreme spatial and temporal variability with rainfall variation coefficient of 0.12 to 0.97 [2,3]

Internal renewable water resources
Surface water, actual : 120 km³/a ; 70% of runoff in June-August (2011) [1,2]
Groundwater, actual: 20 km³ (2011)[1]
Total renewable resources, actual: 122 km³ (2011) [1]

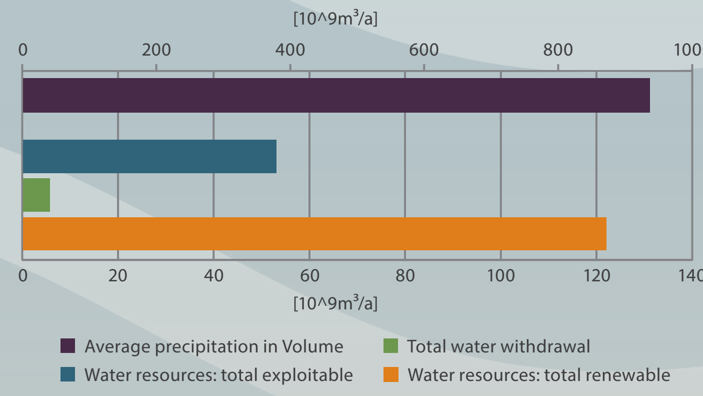
Drainage/Desalination water: data not available/-
Treated municipal wastewater: not available

Balances
Surface water entering the country, natural: 0 km³/a (2011) [1]
Surface water leaving the country, natural: 97 km³/a (2011) [1]
Outflow water secured/submitted to treaties, actual: 0/- (2011) [1]

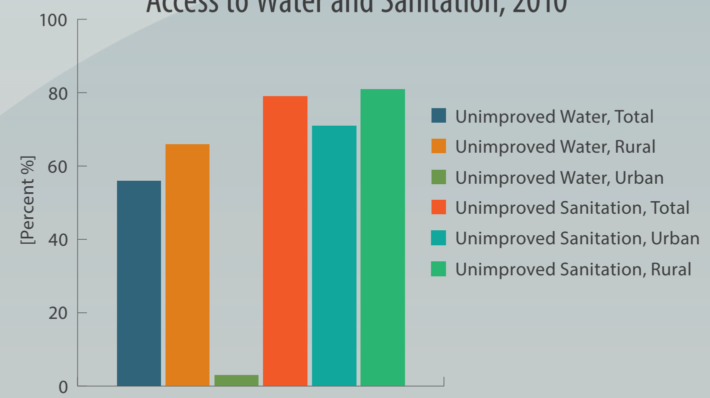
Water Withdrawal by Sector, 2004



Water Production and Consumption, 2004



Access to Water and Sanitation, 2010



90% of total Nile flow situated in Ethiopia [10]
70% of large commercial agricultural system in the Nile Valley [10]
High spatial disparities in water availability creating conflicts in use [2]
Rising transboundary water conflicts, rising demand in agriculture and energy sector [10]
Access to water is low (around 40%) and access to improved sanitation is lacking in most areas [4]

Water for Energy

Hydropower
In Ethiopia many small, medium and large reservoir dams are located along the rivers with a total estimated dam capacity of 5.56 km³ [2]. 99% of totally generated 5109 GWh in 2011 were produced by hydropower [4, 7]. Only two of nine large dams are used for electricity generation, and one is for shared usage of electricity and irrigation. With huge hydro potential unused, the government is building new dams – e.g. the Grand Renaissance Dam [11].

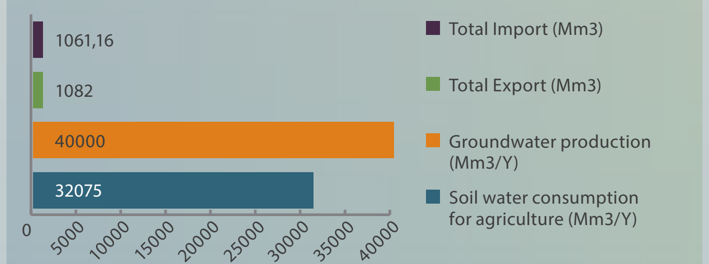
Biofuels
High water availability in Ethiopia makes the production of biofuels attractive. The use of reused water is not necessary for this process. For the government of Ethiopia, biofuels represent an opportunity to enhance food security and assure energy security. Investment in biofuels has been strongly promoted to both national and international companies, and vast tracts of land are granted to foreign companies for production and export to European countries.

Water for Land/Food

Water Efficiency and Cropping Patterns
Crops in Ethiopia are grown during the two main rainy seasons, the Meher and the Belg. The irrigated area in agriculture accounts for less than one percent of the total agricultural area, and solely surface water is used for irrigation. Technologies are not very developed, and sprinkler irrigation accounts for two percent of total irrigation systems. Ethiopia suffers from a food deficit in light of rapidly growing population. Even in good rainy seasons, the food supply can not be met.

Virtual Water
[6] Major irrigated crops associated with virtual water content are soya, cotton and tobacco. The main crop exported and associated with virtual water is coffee.

Virtual Water Agriculture, 2006



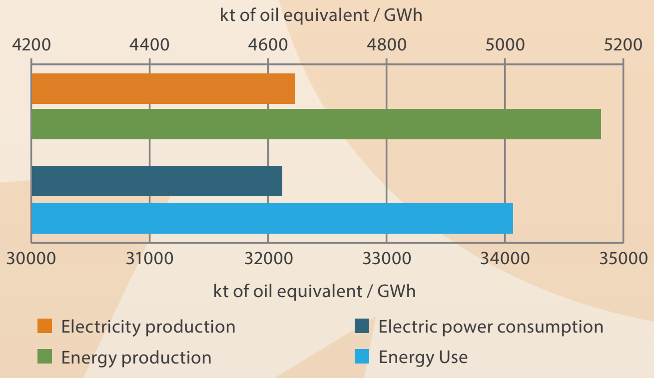
Pollution
Water pollution problems such as salinization are not predominant. However, a systematic water quality assessment is missing. In some regions, water quality is low due to natural conditions and anthropogenic influences [12]. Sewerage treatment is nearly non-existent, and wastewater is directly discharged into rivers. According to the FAO, water quality is not seriously affected by drainage water from irrigation fields due to dilution factors. In the lowlands, hardly any drainage water is discharged [4].

Nexus Country Profile Energy

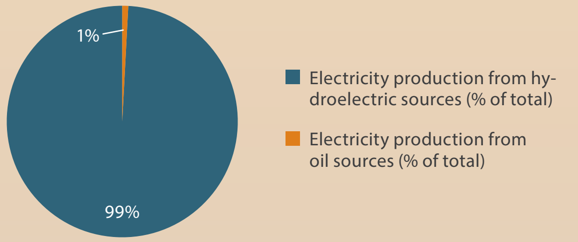
Energy use per capita: 381 ktoe/cap (2011) [1]
Electric power consumption per capita: 52 kWh/cap (2011) [1]
TPES: 34.06 Mtoe (2011) [2]

Reserves and Potential:
Crude oil reserves: 430,000 bbl (2013) [3]
Natural gas: 24.92 billion m^3 (2013) [3]
Coal reserves: 61 Mt [4]
Solar potential, yearly average daily radiation: 4.55 to 5.55 kWh/m^2 [5]
Biomass potential: no specific data available [5]
Wind potential, average wind speed: 100 GWh, 3.5—5.5 m/s [5]
Geothermal potential: 700—5000 MW [5]
Falling water, total hydraulic resources: 650,000 mio. kWh (2008) [6]

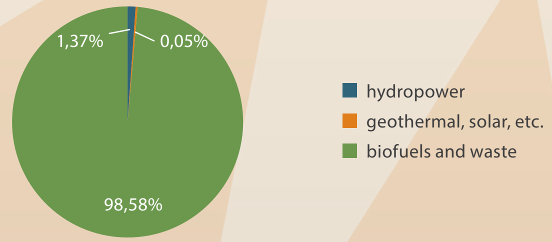
Energy Production and Consumption 2011



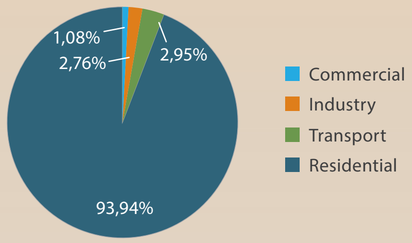
Electricity Production, 2011



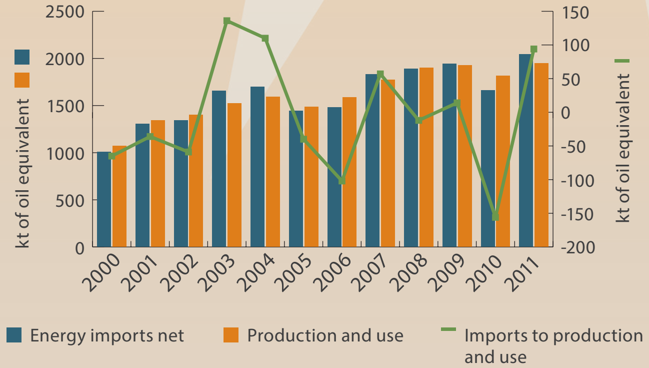
Energy Production Sources, 2011



Energy Use by Sector, 2011



Energy Imports Exports Balance



Current energy surplus is exported to Sudan.
Low access rate to electricity, around 23% in 2011 according to the World Bank.
- Hydropower most viable resource (99% of electricity production in 2011 according to the World Bank) with 5% of the potential exploited [12]
- Government plans to expand hydropower development with capacities of plants of up to 5200 MW and enhance agrofuel development.
- CO2 emissions per capita 0.1 metric tons/a in 2010 [1]
- Methane emissions in energy sector = 10.7 MT of CO2 equivalent in 2010 [1]

Energy for Water

Ethiopia is located at the Horn of Africa. In the central plateau, where most of the population lives, the altitude varies between 2,000 and 3,000m. The rural areas in Ethiopia often are lacking access to electricity, and water extraction from groundwater sources is commonly organized by handwells or petrol driven wells [18]. An increase in water services coverage will lead to higher energy use. In addition to hydropower, the government is being supported in using solar and wind energy for water pumping in rural areas. In general, the low energy use in the water supply sector is due to very low water access. Drinking water supply networks almost do not exist. Major towns represent some exceptions. Because predominantly gravity driven distribution networks are installed, pumps are not commonly used. Leakages can be common in the water distribution networks and can be diminished by the use of pumps. Specific data on the energy use of pumping systems are not available.

Energy for Land/Food

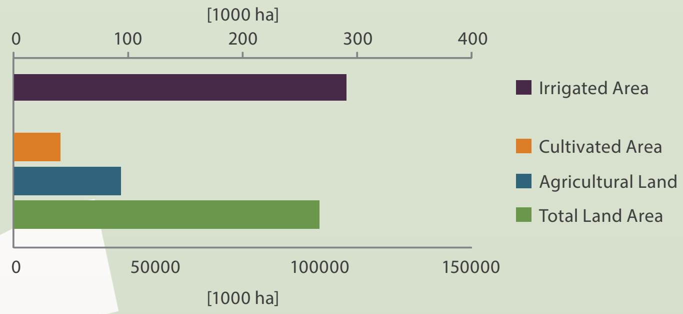
Energy Use in Agriculture
The energy use in agriculture amounts to 84 ktoe, which represent 0.3% of total energy consumption in Ethiopia [2]. This small number contradicts the high importance and contribution to GDP. Reasons for this are the low mechanization, dominance of rain-fed agriculture and low level of development of the sector. Further data on the specific use patterns are not available.

Machinization
Tractors were introduced in 1965 in Ethiopia and contribute now to major import goods [7,8]. According to the World Bank, tractors in use in Ethiopia represent a stagnant number of 3000, while data of FAO illustrate a highly increasing trend in investment in mechanization - 2.8 million US$ in 2004 compared to 16.7 million US$ in 2005. Although this trend could lead to higher agricultural yields, the increase would be mainly driven by expansion of agricultural areas. Agricultural systems are predominantly based on small scale farming using either hand power or draught animals [7].

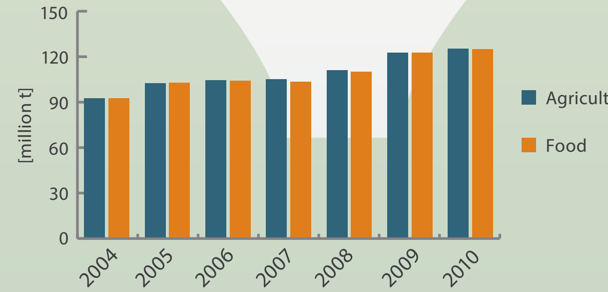
Nexus Country Profile Land

Agricultural land per capita: 0.43 ha/inh (2009) [1]
Cultivated land per capita: 0.18 ha/inh (2011) [1]
Food production per capita, Gross PIN: 119 (2012) [13]
Agriculture to GDP: 46% (2011) [1]
Employment in agriculture: 80% of total pop. [1]
Prevalence of undernutrition: 40% (20010-12) [13]
Share of food consumption expenditure: 51% (2004)
Food supply per capita: 2007 kcal/capita/day (2009) [13]
Production Systems:
mixed farming without specialization in the high and lowlands, shifting cultivation in the south and west, pastoral complex systems, commercial agriculture[3]
Main production commodities,quantity: maize, roots, milk (2012) [13]
Main export commodities, value: coffee, sesame, vegetables (2011) [13]
Main import crommodities, value: wheat, palmoil, sugar (2011) [13]

Land use



Production Index



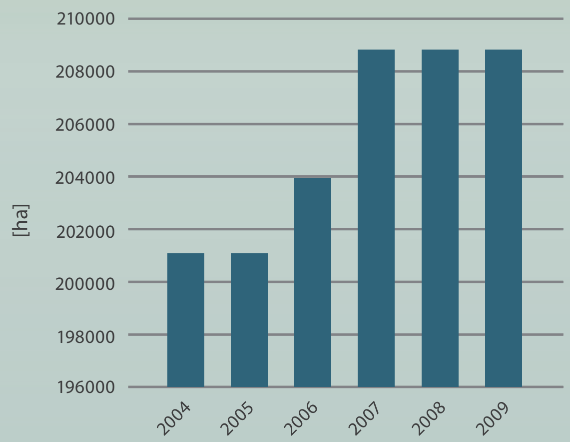
Food Imports and Exports

- Predominantly, non-mechanized and small-scale faaming system < 2ha (83% in 1999)
- High dependence on food aid deliveries – around 6 mio people - due to uncertain rainfall, land degradation and drought [4]
- Yields at very low levels compared to international standards [4]
- Huge promotion in foreign investment in land – around 3.6 mio ha offered for investement [16]
- High deforestation due to unregulated land acquisition [14]

Land for Water

Protected Areas
In Ethiopia, the proportion of terrestrial protected area is 18%. Water and soil conservation have been widely introduced but monitoring techniques still seem to be lacking [1,6]. Large wetlands account for 1.5% of total area [7]. They serve a source for groundwater recharge, provide baseflow during dry seasons and mitigate flooding [5]. Several wetland areas have been given to investments without clear evidence of existing withdrawal limitations [14]. According to UNEP, 71.5% of total land area is impacted by the desertification caused by deforestation, overgrazing and poor farming practices [15].

Marine Protected Areas

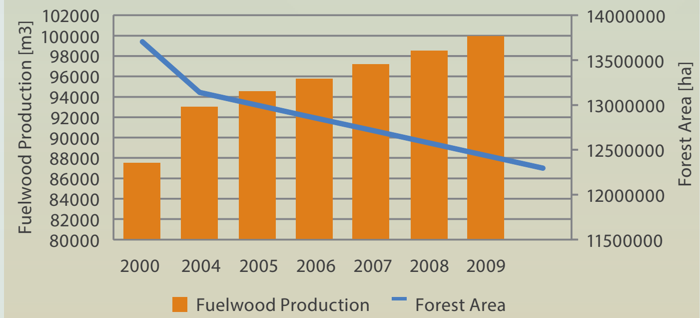


Reservoirs
The installed capacity of dams in Ethiopia is 5.56 km^3 [5]. In total nine large dams are in operation, of which two are used for irrigation in agriculture. Several small dams and resevoirs are located in the Amhara and Tigray regions. The accessible surface area covered by dams is 720 km^2 [8]. The Grand Renaissance Dam under construction will cover an area of 1900 km^2 [9].

Land/Food for Energy

Land for Fuelwood
Fossil fuels are economically unaccessible to the local poor population, resulting in a wide use of fuelwood and illegal logging. Two bio. sqm of soil along with 200,000 ha of forest cover are lost annualy, reducing the yield potential by 2% each year[17]. The government is involved in national priority actions focusing on forestation.

Forest Area and Fuel Wood Production



Land for Biofuels
The total area for biofuels is estimated around 1.15 mio. ha, and 500,000 ha are offered for investements [10]. For biodiesel, jatropha and castor bean represent the most efficient crop. Ethanol is derived from sugar cane grown on large scale plantations. The production of ethanol experienced an increase up to 15,000 m^3. [11] Ethiopia seems to have an enormous potential for biofuels with 25 mio. ha of land area. For Ethiopia, biofuels are an opportunity to decrease food insecurity via technological transfer and the use of revenues for food purchases.

Ethiopia
Rapid Assessment

Nexus
Water | Energy | Food Security

Overall Assessment

NEXUS CHALLENGES

Ethiopia, located at the Horn of Africa and with over 100 million inhabitants, is the second-most populous nation on the African continent after Nigeria. In the central plateau, where most of the population lives, the altitude varies between 2,000 and 3,000 m.

Since 2007, Ethiopia has achieved strong economic growth, making it one of the highest performing economies in sub-Saharan Africa. Yet, it remains one of the world's least developed countries, ranked 174 out of 187 in the 2011 UNDP Human Development Index and 70 out of 76 in the 2012 Global Hunger Index. About 29% of the population lives below the national poverty line (IFAD 2012).

Ethiopia's economic structure is unique in Africa. It has no oil or mining sector, and private investment is relatively new. With the country lacking basic growth components, the Ethiopian economy is highly dependent on agriculture.

Ethiopia remains one of the world's most food-insecure countries, where about one in three people live below the poverty line. Ethiopia has high spatial disparities in water availability that create conflicts on local as well as transboundary levels. More than 8 million people are currently suffering from drought conditions.

Ethiopia covers its electricity demand almost completely with hydropower. Still, the rural population has no access to energy; thus, the use of fuel wood is widespread. The resulting deforestation increased soil degradation and leads to water stress, drought, and crop failure , thus influencing food security and reducing the potential for biofuel production.

Ethiopia suffers from a food deficit, while the population is rapidly increasing. Even in good rainy seasons, the demand for food cannot be met.

SOLUTIONS

The major reasons for food, water and energy insecurity in Ethiopia do not relate to a lack of resources but are mainly governance born (infrastructure development, insecurity and conflict, poverty, fall in world prices of cash crops).

Despite the liberalisation of Ethiopia's market for international investment, the state is still the most dominant actor. However, foreign investments and thus financial resources are increasing with strong enforcement of regulations by the government. If this continues, increased investments could accelerate the progress in Ethiopia's many WEF security issues.

In terms of water security, Ethiopia needs to prevent national water conflicts by ensuring water security. Increased water storage for drought-affected areas and extended public services that include safe drinking water supply and sanitation services could impact the disparities in water availability positively.

Furthermore, the increase of energy accessibility would have a positive effect on water security, because it would open the option for the rural population to upgrade their techniques to independently access safe water sources.

An increased energy demand caused by improved water services coverage could be covered by hydropower and biofuels.

Besides, biofuels are an opportunity to decrease food insecurity via technological transfer and the use of revenues for food purchases.

Water Security

Ethiopia has high water availability with 90% of the Nile flow in the country and two rainy seasons. Still spatial disparities in water availability exist. Water governance in Ethiopia is very poor.

Water supply ●●○○○
The rural population has low to no access to safe water sources. Water conflicts exist on local as well as transboundary levels.

Virtual water ○○○○○
Major irrigated crops associated with virtual water content are soya, cotton and tobacco. The main crop exported and associated with virtual water is coffee.

Protected Areas ●●●○○
Protected areas are increasing with large initiatives to promote these areas for tourism.

Reservoir ●●○○○
Reservoirs are increasingly being used for irrigation. There are still few of such small multi-purpose reservoirs.

Pollution ●○○○○
The access to sanitation is insufficient, and sewerage treatment is nearly non-existent, thus leading to water pollution through direct discharge into the environment.

Energy Security

Ethiopia has a high availability of potential energy sources. For the water rich country, biofuels are an opportunity to enhance food security and ensure energy security and hydropower are a constant source of electricity. Still, the rural population has no access to energy/electricity. Thus, and because of the economical unavailability of fossil fuels, fuelwood is used.

Biofuels ●●●●●
In Ethiopia, a large portion of energy is produced by biofuel and waste. Investment into biofuels is increasing and has been strongly promoted.

Land for Biofuels ●●●●●
Ethiopia seems to have an enormous potential for biofuels with 25 mio. ha of land area. The total area for biofuels is estimated around 1.15 mio. ha and further 500,000 ha are offered for investments.

Fuelwood ●○○○○
The wide use of fuelwood and illegal logging reduces the yield potential by 2% each year.

Wastewater for Energy ○○○○○

Hydropower ●●●●●
Hydropower makes up 99% of the totally generated electricity, and large investments (e.g. the construction of the Grand Millennium Dam) have been made.

Fossil fuels ●○○○○
Economically not accessible to the local poor population.

Access to Electricity ●○○○○
The rural population has no access to energy/electricity.

Food Security

In Ethiopia, agriculture is the foundation of the economy, employing 80% of the country's 82 million people. Some 85% of the population lives in rural areas and is, thus, mainly engaged in rain-fed subsistence agriculture. Still, Ethiopia fails to cover its increasing population's food demand, leading to 40 % of the population being undernourished (FAO, 2013) and 4-5 million Ethiopians constantly depending on external food supply through donor organisations. Food production is mainly depended on rain and highly dominated by small-scale farmers who largely depend traditional agricultural practices.

Cropping patterns ○○○○○
Ethiopia has two rainy seasons. Main production commodities are maize, roots, milk (2012).

Energy use in Agriculture ●●●●○
An unmechanized, small scale farming system results in a low energy use in agriculture.

Food markets ●○○○○
Availability and functioning of local food markets is, alongside the volatility of international markets, a big challenge for food security in Ethiopia.

Productivity in Agriculture ●○○○○
Ethiopia suffers from food deficit, even in good rainy seasons the food demand can not be covered.

Rating

The rapid assessment of the situation above, based on available data, was established following the UN Water Country Profiles. It provides an overview of trends according to the following:

○○○○○ *insufficient data*
●○○○○ *trends are of significant concern*
●●○○○ *trends are of concern*
●●●○○ *trends are stable or progressing on certain issues but not on others*
●●●●○ *trends show some measure of improvement in all relevant indicators assessed*
●●●●● *trends show significant improvement and there is no concern*

Nexus
Water | Energy | Food Security

Ethiopia

Nexus Country Profile

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https://www.th-koeln.de/
http://www.water-energy-food-nexus.info/

Useful Resources:

Data Sources:

World Bank Country Database
IEA Statistics
FAO Country Profiles Database
FAO Aquastat Database

Nexus Websites:

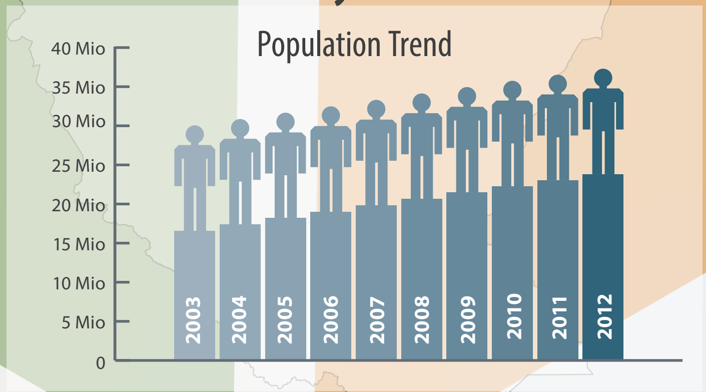
www.water-energy-food.org
www.thenexusnetwork.org
www.gracelinks.org
www.futureearth.org

Nexus

Water | Energy | Food Security

Sudan

Nexus Country Profile



Country Data

Total land area (ha): 237,600,000 [3]
Population density (people per km^2 of land area): 20 (2011) [1]
Population growth (annual %): 2.1 (2012) [1]

GNI per capita (2005 PPP $): 1,591 (2012) [2]
Unemployment total (% of total labour force): 18 (2012) [8]
GINI coefficient: 35.3 (2011) [1]
Poverty gap at national poverty line/ at 1.25$ (PPP) (%): 16/ 5 (2008) [1]
HDI (value/rank of 187): 0.414/ 171 (2012) [2]
MPI value: no data available [2]
GII (value/rank of 148): 0.604/129 (2012)[2]

Mean years of schooling: 3.1 (2012) [2]
Literacy rate adult total, 15 and above (%): 72 (2011) [1]
Life expectancy at birth (total years): 62 (2011) [1]
Mortality rate under 5 (per 1000 of live births): 73 (2012) [1]

GDP and WEF Sector

GDP per capita (constant 2005 US$): 836 (2012) [1]
GDP growth annual (%): 3.1 (2011) [1]

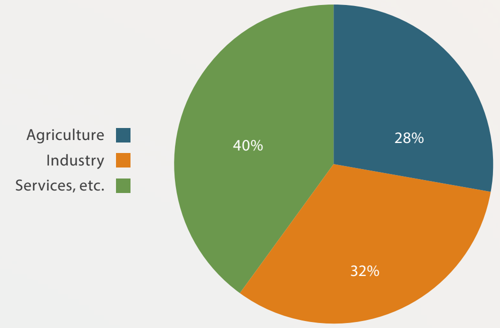
Government revenues (bio. LCU): 22 (2012) [8]
Government spending (bio. LCU): 31 (2012) [8]
Inflation, GDP deflator (annual %): 34 (2012) [1]

Tax revenue (% of GDP): no data available
Subsidies and other transfers (% of expense): no data available

Consumption and Foreign Inflows

General government final consumption expenditure (constant 2005 US$/% of GDP): 4,795 mio. /12 (2008) [1]
Household final consumption expenditure/ per capita (constant 2005 US$): 21,731 mio./ 504 (2008) [1]
Foreign direct investment net inflows (mio. US$/% of GDP): 56,493.2/4 (2000-2008/2012) [6, 1]
Net ODA received (% of central government expense): no data available [1]
Agriculture (source denotes incomplete data)

Sector Contribution to GDP, 2008



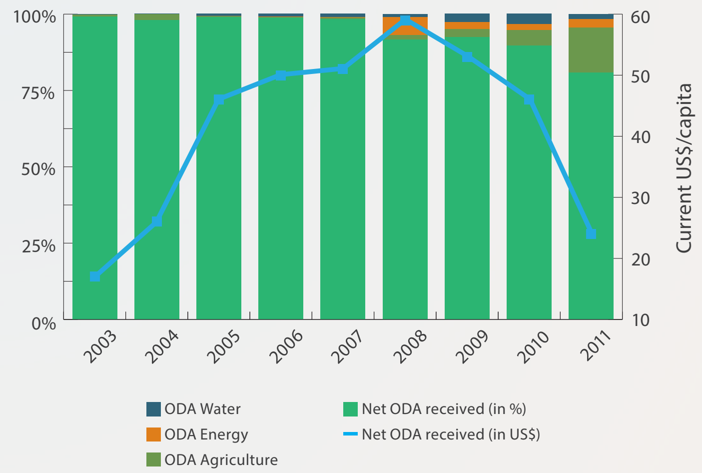
Investment and Sector Finance

Total land area allocated by FDI (ha): 471,660 to 1,133,100 + 400,000 in South Sudan (signed & under preparation) [6,5]
FDI capital investment agriculture sector (mio. US$): 1,045.82 (91.3% Arab countries) (2000-2008) [6]
Public investment in agriculture (% of GDP): 0.9 (2004) [7]
[6,5] Deals mainly between governments, main investor Arab Countries with 91% of total FDI; 86.4% of total FDI capital in Khartoum, Northern and Central Sudan; although large increase in total investment- only 2% into agriculture sector, 81% industry, 17% into services, most datasets incomplete [6,4]

Water
Federal expenditures, water (% of GDP): 0.3 (2006) [11]

Energy
Fuel subsidies account for 15% of expenditure in 2012 (IMF cited in eia) [12]

Official Development Aid in Sectors



Nexus Country Profile Water

Water available per capita: 1.411 m^3/a (2011) [1]
Water consumption per capita: 683.4 (2005) [1]

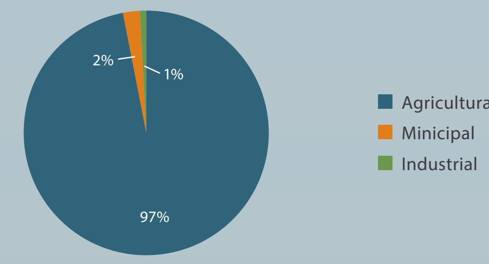
Rainfall average: 416 mm/a [2]
Rainfall distribution spatial: 25 to 1600 mm/a [2]
Rainfall distribution temporal: erratic spatial and temporal distribution with rainfall variation coefficient of 0.3 to 1, recent slight decrease in annual rainfall and increased vulnerability due to droughts [2]

Internal renewable water resources
Surface water : 62.5 km^3/a [1]
Groundwater: 7 km^3/a [1]
Total renewable resources: 64.5 km^3/a [1]

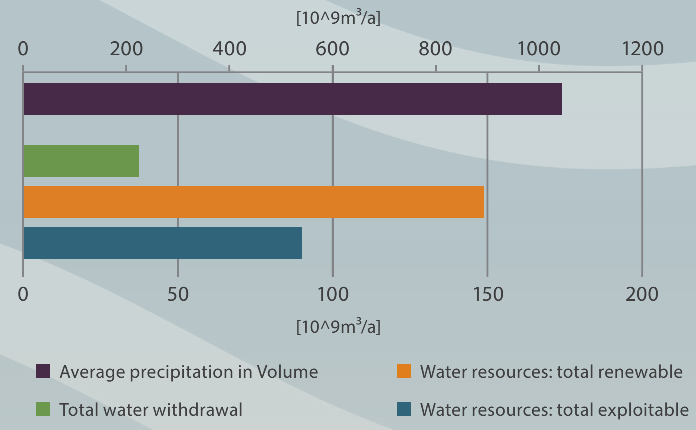
Additional Sources
Drainage water: no data available
Treated municipal wastewater: no data available
Desalination: 2 plants with capacity of 0.024km^3/a in Port Sudan [3]

Balances:
Surface water entering the country, natural: 119 km^3/a (2011)[1]
Surface water leaving the country, natural: 84 km^3/a (2011) [1]
Outflow secured/submitted through treaties: 65.5, 84 km^3/a

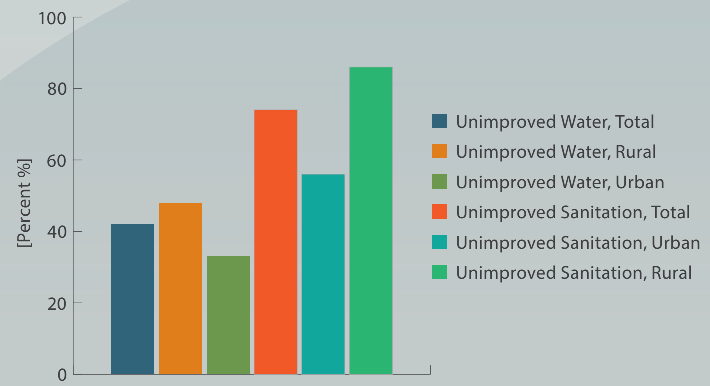
Water Withdrawal by Sector, 2004



Water Ressources and Consumption, 2004



Access to Water and Sanitation, 2010



South Sudan has one of the highest infant and child mortality rates in the world with 67 deaths per 1,000; for the north, the numbers are slightly lower with 49 deaths per 1,000. Water contamination has several sources and lack of adequate sewage treatment represents one of them. According to the World Bank, 43% of the population use open defecation. Water-borne diseases, due to a lack of adequate sewage treatment facilities, make up 80% of all reported diseases in Sudan [5].

Water for Energy

Hydropower
Sudan has eight known reservoirs, of which the Shereyk Dam and the Kajbar Dam are under construction. According to the UNEP, the total designed storage capacity of 8.58 km^3 for the larger dams has losses in the range of 60% to 34% [5]. Siltation processes affect all large dams in Sudan except the Jebel Aulia. With the extension of the Roseiries Dam in 2012, the capacity of the reservoir is estimated to be 7.4 km^3. The main objectives of these reservoirs are flow control and increase of the irrigation potential and secondly generation of electricity. The total and actual numbers on the current storage capacity in Sudan are not available.

Biofuels
Sudan is the third largest sugarcane producer in Africa. Production of biofuels from byproducts of sugar is concentrated mainly on ethanol and secondly on biodiesel. [11] Currently sugar is cultivated on five major irrigation schemes and in an area of 200,000 ha. Total production experienced an increase of 77% within 18 years, and the government is further planning to expand the area to 1.4 mio ha. A very significant but largely unquantified issue is water pollution and direct discharge of effluent by sugar factories. UNEP reported that the BOD of this wastewater can reach 800 to 3,000ppm and, therefore, significantly affect the water body and fish population.

Deforestation rates in Sudan are high. Although the importance of forests for management of water resources has been widly recognized, deforestation is proceeding. The loss of riverine forests is correlated with increasing sedimentation, high loss in storage capacities of reservoirs, regulation of watersheds and increasing vulnerability to floodings[12].

Water for Land/Food

Water Efficiency and Cropping Patterns
A study conducted by El-Amin (2011) reported that water use efficiency in the Gezira scheme is low and overirrigation could be found for each crop analyzed. The yield gap for rainfed crops amounts to 90%[6]. On the contrary, AARINENA found out that farmers in Karthoum generally apply too low amounts due to high pumping costs. Cotton, extensively grown in the past, represents the most water consuming crop and experienced a high decrease in cultivation [8]. Sudan as a large country has distinctive vegetative cover and cropping patterns. In the northern part, where rainfall is low, agriculture is based on traditional rainfed farming.

Virtual Water
[10] Mainly livestock affects the balance for virtual water exported with 2503 compared to crops with 652 Mm^3/a. Major crops associated with virtual water are cotton, sugar or wheat.

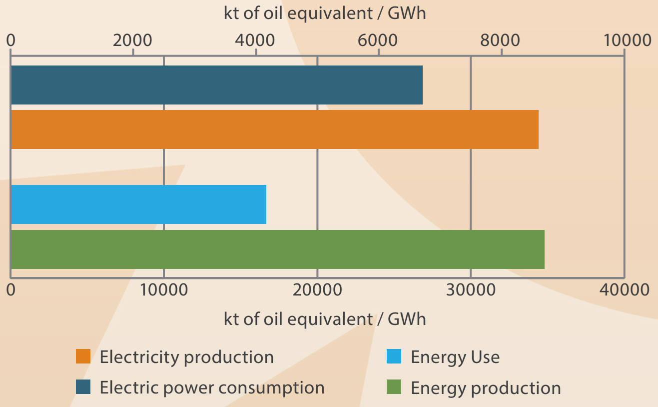
Pollution
Water pollution in Sudan is a chronic crisis due to completely missing treatment facilities and is seen a serious concern for the future. [5] Industrial development in Sudan is low; as a result, environmental damage has been minimized.
Fertilizer consumption in agriculture of 11 kg applied per ha is low [4]. Subject to many different farming scales and ownerships, chemical concentrations and types can vary. UNEP reported that pesticides applicated on cotton and wheat fields use high concentrations of DDT. As monitoring programs do not exist, this especially represents a major obstacle and the most serious threat to human health in areas where the population is dependent on these resources for drinking water.

Nexus Country Profile Energy

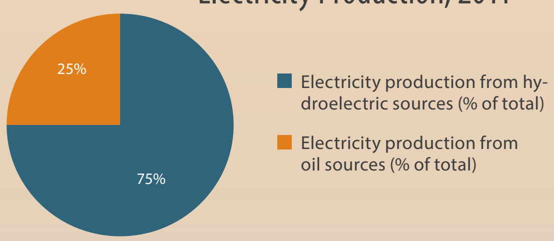
Energy use per capita: 355 ktoe/cap*a (2011) [1]
Electric power consumption per capita: 143 kWh/cap*a (2011) [1]
TPES: 16.62 Mtoe (2011) [2]

Reserves and Potential:
Crude oil reserves: 5 bio. barrels (75% located in South Sudan) (2013) [3]
Natural gas: 82.95 billion m^3 (2013) [3]
Coal reserves: None (2007) [4]
Solar potential: 8,702 TWh (2008) [5]
Biomass: 15.1 mio. m^3(forest wood), 55.5 MW (sugar molasses), plans for 60 mio. l bioethanol and 50 mio. l biodiesel [6]
Wind potential, wind speed: 0 [5], 3-6 m/s [6]
Geothermal potential: 400 MW [6]
Falling water, total hydraulic resources: 48,000 mio. kWh/4,920 MW (2009/n.d.) [7,8]

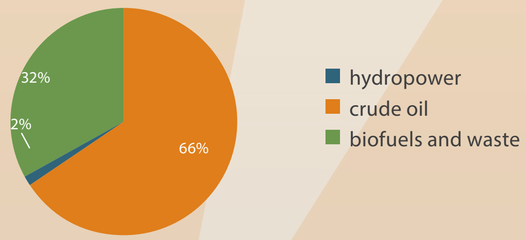
Energy Production and Consumption, 2011



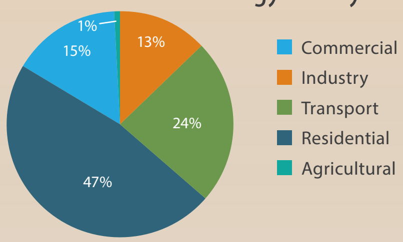
Electricity Production, 2011



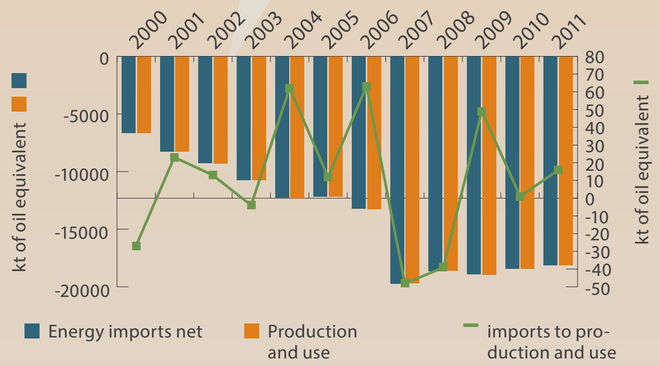
Energy Production Sources, 2011



Energy Use by Sector, 2011



Energy Imports Exports Balance



Energy production highly dependent on oil with instability of supply after the independence of South Sudan
- Low access rate to electricity, around 30% in 2011 according to the World Bank.
- Hydropower most viable resource, around 75% of electricity production in 2011 according to the World Bank.
- Government plans import energy from Ethiopia and construct new hydropower plants with foreign investments.
- High distribution losses (around 22%), not including extreme losses in the dams due to siltation processes.
- Per capita emissions of CO2 around 0.3 kt with an overall amount of 14,173 kt in 2011.
- Methane emissions in the energy sector resulted in 7,154 metric tons of CO2 equivalent for 2011. [1]

Energy for Water

In Sudan, water supply is mainly regulated by diesel driven water pumping units [13]. As in 1980, the demand for convential energy could not be covered in rural areas; the government decided to enhance the development with the installation of wind pumps for water supply[11]. Water distribution in Sudan is reported to be very cost intensive, and thus in recent years there has been a significant increase in renewable energy systems in rural areas in order to reduce the capital cost for energy consumption [14]. While in the past, large scale irrigation in agriculture was practiced by gravity systems, pumping technologies became important in the 20th century with flood irrigation and waterwheel techniques [12].

Energy for Land/Food

Energy Use in Agriculture
The energy use in agriculture is very low, with 87 ktoe in 2011, compared to international standards. Electricity use in this sector accounts for 26 ktoe, while 61 ktoe represent the use of oil products. [2]

Machinization
Investments in agricultural machinery show a steady expansion. In 2004, agricultural machinery in use were 16,639 tractors and increased to 25,564 tractors in 2008 [1]. Mechanized farming in Sudan experienced a high increase with an area of 12.6 mio. ha in 2001, compared to 7.93 mio ha in 1995 [10]. Machinery is used in farming systems with large scale commercial rain-fed cultivation in the dry and wet savanna of Sudan.

Case Study: Gezira Scheme
The Gezira scheme is the largest gravity driven irrigation system of Sudan. According to studies of the FAO, the area of irrigated agriculture using pumping was at 346,680 ha in 2000, and the area equipped for full or partial control irrigation accounts for 1,730,970 ha. According to estimations calculated by ERAF, 3.6l of diesel are needed to pump 13.9 m^3 of water and a head of 50m. Specific data on energy or electricity consumption for water distribution are not available.

Nexus Country Profile Land

Agricultural land per capita: 4.15 ha/inh. (2009) [2]
Cultivated land per capita: 0.61 ha/inh (2007) [2]
Food production per capita, Gross PIN: 101 (2011) [5]

Agriculture to GDP: 24% (2011) [1]
Employment in Agriculture: 52% (2011) [1]

Prevalence of undernutrition: 39% (20010-12) [5]
Share of food consumption expenditure: 61.4% (2009) [3]
Per capita food supply: 2227 kcal/capita/day (2009)[5]

Production Systems: large irrigation schemes and agropastoral subsistance farming[4], [13]

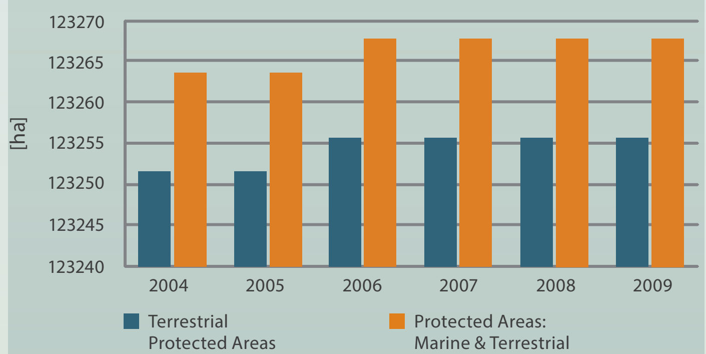
Main production commodities, quantity: cereals, coare grain, meat (2011)[5]
Main export product, value: sesame, cotton, sheep meat (2011) [5]
Main import product, value: wheat, sugar, coffee (2011) [5]

Land use

Land for Water

Protected Areas
The proportion of protected areas in former Sudan accounts for 4.2% of total land area [1]. The protected areas differ in terms of type and management between North and South Sudan, but, due to historical and ongoing conflicts, the availability of data is highly skewed. UNEP reported that water pollution is a serious concern. Missing monitoring programs and environmental regulations on protection of water body cause a high threat to nature and the population.

Terrestrial and Marine Protected Areas



Reservoirs
Sudan has, in total, five hydropower stations and reservoirs, which cover a total surface area of 3,114 km^2 [10]. The potential of hydropower is high, and several dams are under construction.

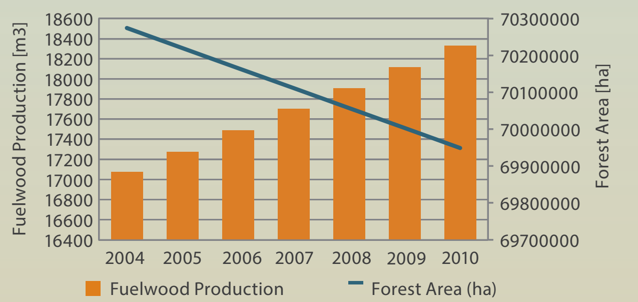
Food Imports and Exports

Sudan has a high agricultural potential but due to inadequate water resources and difficulties in transport much of the arable land area is not used. Efforts undertaken to push for high investment by oil rich neighbours have been carried out since the 1970s to develop Sudan as a major food producer for the Middle East[6]. With the independence of South Sudan, the northern part of Sudan has made a lot of investments in agriculture to drive the economy and to decrease the dependence on oil as main export product. To establish agriculture, large areas of forests were cleared, resulting in severe land degradation and increased vulnerability to droughts and ongoing desertification [9]. Irregular rain affects the yields and causes spatial food deficit. Production of meat and paddy rice increased substantially in the period of 1996 to 2011, while other commodities remained stagnant or decreased, such as wheat [5].
With a poverty ratio of more than 50% living on 1$ per day, South Sudan is one of the poorest countries worldwide [1]. Despite the high potential in cultivation, the infrastructure is almost completely lacking, and there is no access to markets due to disrupted food corridors. [8] Conflicts, a below average harvest, high production and transport cost and food speculations of food prices are driving the food insecurity in Sudan, and the situation is becoming more critical as the further displacement of people is causing larger losses in yields. At the moment, in South Sudan, 3.7 mio. people are facing acute emergency levels, major food security and nutrition crisis.

Land/Food for Energy

Land for Fuelwood
Biofuels and waste represent a major energy source, and fuelwood is important as poverty is widespread [1,11]. Deforestation occurs throughout Sudan [9]. Theoretically, forest authorities regulate commercial logging, but in practice this process is much less controlled. In the period between 1990 and 2005, Sudan lost 11.6% of its total forests, and deforestation is leading to land and water degradation.

Forest Area and Fuel Wood Production



Land for Biofuels
12] Biofuels are emerging as an important energy source. Sudan is the third largest sugarcane producer in Africa. Production of biofuels from byproducts of sugar is concentrated mainly on ethanol and secondly on biodiesel. Currently, sugar is cultivated using five major irrigation schemes and an area of 200,000 ha. Total production experienced an increase of 77% within 18 years, and the government is furthermore planning to expand the area to 1.4 mio ha.

Sudan
Rapid Assessment

Nexus
Water | Energy | Food Security

Overall Assessment

NEXUS CHALLENGES

Sudan continues to struggle with the macroeconomic aftereffects of South Sudan's secession in 2011, as the country lost 75 % of oil output and almost 60 % of its fiscal revenues. Precarious employment and the absence of publicly financed safety nets severely increase the impacts of food, energy and water insecurity on the population.

At least 70 % of the Sudanese population relies on traditional rainfed agriculture and livestock production for food and income. Constant rural-urban migration weakens the agricultural productivity and deepens poverty in both urban and rural areas. As urban populations continue to grow, competing demands for urban and agricultural uses of water increase the stress on the already declining water resource. Hence, problems of irrigation as well as transportation remain the greatest constraints to develop a a more dynamic agricultural economy.

Yet, the farming practices have reduced the arable soil and have caused desertification to spread. Continuous deforestation due to logging of firewood further increases these effects and leads to severe land degradation. Moreover, the loss of riverine forests increases siltation of reservoirs, which reduces their holding capacity and their use for agriculture as well as energy production.

In addition, climatic phenomena like the El Nino warming impacts Sudan's heavily rain dependent food security.

Serious concerns for the future of water security in Sudan are raised due to the changing water use of the upstream countries as well as by the constant water pollution resulting from the absence of treatment facilities.

SOLUTIONS

Conflicts over natural resources have to stop; cooperation and environmental governance has to increase

Natural resource assessment and management strategies should be increasingly included into peace building and peacekeeping efforts.

It is widely agreed that the primary users – those who directly depend upon the natural resource for their livelihood, for example farmers and pastoralists in the case of Sudan – should have the greatest entitlement.

Renewable energy systems in rural areas can become a viable low-cost energy-supply option.

In regard to land issues, it is important to put a hold on increasing deforestation by providing alternative energy production technologies. Besides, the economic importance of livestock for pastoral livelihoods must be recognised. This is ensured by taking account of customary procedures in NRM and reinstating endogeneous mechanisms for conflict arbitration and resolution.

Water Security

The livelihood of Sudan depends on its water security. Eighty percent of the country works in agriculture, which accounts for 97% of its water use. Sudan has a very high water use per capita (1,897 m^3/a) and suffers from a water deficiency and cannot cover its water demand for agriculture and other essential uses. With population growth the water demand is expected to double by 2050. ´

Most of Sudan's currently accessible groundwater is shared with surrounding countries. Sudan utilizes shares of the water from the Nile river, but its use is not regulated by the government. This unrestrained use of shared water, mostly for irrigation and energy, creates tension with neighbouring countries like Egypt and Ethiopia.

Water security on a household level is affected by a lack of adequate sewage treatment facilities. Water borne diseases make up 80% of all reported diseases in Sudan and cause the highest infant and child mortality rates in the world with 49 deaths per 1,000.

Water supply ●●●○○
There is high access to safe water through diesel and wind driven pumps, whereas 43% of the population rely on open defecation.

Reservoir ●○○○○
There is high loss in storage capacities of reservoirs due to increasing sedimentation.

Virtual water ○○○○○
Livestock negatively affects the balance of virtual water exported.

Pollution ●●○○○
There is high discharge of untreated excreta into water bodies as well as pollution of groundwater and high concentrations of DDT in potable water storages due to the use of pesticides in agriculture.

Protected Areas ●●○○○
Missing monitoring programs and environmental regulations on protection of water bodies cause a high threat to nature and the population.

Energy Security

Sudan's oil-dependent energy security was severely weakened when it lost most of its oil reserves following the separation of South Sudan. The government plans to import energy from Ethiopia and to construct new hydropower plants with foreign investments. However, high distribution losses occur in addition to high losses in the dams due to siltation processes.

Biofuels ●●○○○
Biofuels are emerging as an important energy source.

Hydropower ●●●○○
Hydropower is the most viable resource. Its potential is high. Further dams are under construction. There is a need for comprehencsive environmental assessment.

Land for Biofuels ●●●○○
Existent plans to expand the area from 200.000 ha to 1.4 mio ha. Effects on soil quality not assessed.

Fossil fuels ●●○○○
High oil-dependency. Access to fossil fuels is a source of conflict between South Sudan and Sudan.

Fuelwood ●●○○○
Fuelwood is an important energy source as poverty is widespread. Deforestation rates in Sudan are high.

Access to Electricity ●●○○○
Low access rate to electricity, around 30% in 2011.

Food Security

Food security in Sudan is threatened by a combination of conflict, insecurity, lack of infrastructure, lack of access to markets and high food prices. Food assistance is delivered to four million people in Sudan, of which the large majority are conflict-affected people. Still, the agricultural potential in Sudan is not utilized.

Cropping patterns ●●●○○
In the northern region, agriculture is based on a traditional rainfed farming. Cotton as a traditional crop experienced a high decrease in cultivation.

Machinization ○○○○○
Much of Sudan's land is cultivated by mechanized farming. This intense agricultural system has reduced arable soil. Mechanization needs to increase to improve productivity.

Energy use in Agriculture ●●●●○
The energy use in agriculture is very low compared to international standards.

Productivity in Agriculture ●●○○○
Subsistence farming and pastoralist communities. Rural-urban migration weakens the agricultural productivity.

Water use efficiency ●○○○○
Most farms are rural and fed by rainwater. Overirrigation in the Gezira scheme due to techical deterioration and management failures.

Food supply ●○○○○
There is a high child malnutrition rate of 31.8%, and 28% of the population was below the minimum level of dietary energy consumption in 2010.

Food markets ○○○○○
Cotton and gum Arabic are the major agricultural exports. Livestock exports to Egypt, Saudi Arabia, and other Arab countries. Local markets are not functioning.

Rating

The rapid assessment of the situation above, based on available data, was established following the UN Water Country Profiles. It provides an overview of trends according to the following:

○○○○○ *insufficient data*
●○○○○ *trends are of significant concern*
●●○○○ *trends are of concern*
●●●○○ *trends are stable or progressing on certain issues but not on others*
●●●●○ *trends show some measure of improvement in all relevant indicators assessed*
●●●●● *trends show significant improvement and there is no concern*

Sudan

Nexus Country Profile

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http://www.water-energy-food-nexus.info/

Useful Resources:

Data Sources:

World Bank Country Database
IEA Statistics
FAO Country Profiles Database
FAO Aquastat Database

Nexus Websites:

www.water-energy-food.org
www.thenexusnetwork.org
www.gracelinks.org
www.futureearth.org

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