UN WATER

Report

The United Nations World Water Development Report 2014

WATER AND ENERGY

VOLUME 1

UNESCO
United Nations
Educational, Scientific and
Cultural Organization

World Water
Assessment Programme

UN WATER

The United Nations World Water Assessment Programme has coordinated the development and production of the WWDR 2014, and has prepared the chapters in Part 1 and Part 4.

The following agencies and regional commissions led and prepared the chapters in Part 2, Thematic Focus, and Part 3, Regional Aspects:

FAO FIAT PANIS
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We wish to thank the other UN-Water Members for their intellectual guidance, useful revisions and timely endorsements:
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Preparation of this report was made possible thanks to the generous financial support of the Italian Government to UNESCO for the United Nations World Water Assessment Programme

The United Nations World Water Development Report 2014

WATER AND ENERGY

VOLUME 1

Published in 2014 by the United Nations Educational, Scientific and Cultural Organization, 7, place de Fontenoy, 75352 Paris 07 SP, France

ISBN 978-92-3-104259-1
ePub ISBN 978-92-3-904259-3

Suggested citation:
WWAP (United Nations World Water Assessment Programme). 2014. *The United Nations World Water Development Report 2014: Water and Energy*. Paris, UNESCO.

The contents of Parts 2 and 3 were contributed by the UN-Water Members and Partners listed on the title pages of the chapters therein. UNESCO and the United Nations World Water Assessment Programme (WWAP) are not responsible for errors in the content provided or for discrepancies in data and content between contributed chapters.

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Cover and interior design and typesetting by Phoenix Design Aid A/S, an ISO 14001 (environmental management) and a DS 49001 (corporate social responsibility) certified and approved carbon neutral company.

Printed by UNESCO CLD, Paris.
This publication is printed with vegetable inks on FSC Mixed Sources paper, supporting responsible use of forest reserves. This is a carbon neutral print product. UNESCO Printing will contribute funds to a project replanting trees in Europe or Africa for this publication.
Printed in France

The United Nations World Water Development Report 2014 has been published on behalf of the United Nations World Water Assessment Programme by UNESCO with the support of the following organizations:

United Nations Funds and Programmes
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United Nations Conference on Trade and Development (UNCTAD)
United Nations Department of Economic and Social Affairs (UNDESA)
United Nations Development Programme (UNDP)
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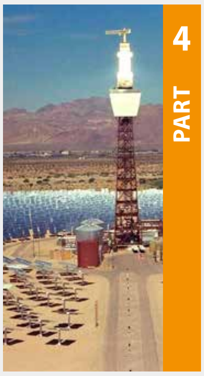

RESPONSES: FOSTERING SYNERGIES AND MANAGING TRADE-OFFS

FOREWORD

by Ban Ki-moon
Secretary-General of the United Nations

Water and energy are inextricably linked. Water is essential for the production, distribution and use of energy. Energy is crucial for the extraction and delivery of safe drinking water – and for the very safety of water itself. People everywhere – but especially the most vulnerable and marginalized – face great risks when access to either is limited or compromised.

This *World Water Development Report* provides detailed analysis of these connections and their implications for the world's pursuit of sustainable development and the Millennium Development Goals. It is the fruit of collaboration by UN-Water, the UN inter-agency coordination mechanism dedicated to all freshwater-related issues.

The Report addresses a wide range of key issues, including agriculture, cities, industry, infrastructure and the environment. Its message is clear: the 'water–energy nexus' is about substantially more than hydropower and biofuels. Water and energy can drive economic growth and improvements in human health. They are enablers for poverty reduction, job creation, women's empowerment and human well-being in general. This was also a central lesson that emerged from last year's observance of the International Year for Water Cooperation. It is also a fundamental premise of my 'Sustainable Energy for All' initiative.

In order to provide modern, affordable and environmentally sound energy and drinking water services for all, we need a sustainable approach to the management of both freshwater and energy resources. This calls, in turn, for far greater coordination. The two key mechanisms of the United Nations system – UN-Water and UN-Energy – will play a critical role in this regard. These issues will also be fundamental elements in shaping the post-2015 development agenda.

The *World Water Development Report* is aimed at policy-makers and the water and energy communities, including scientists across the world. My hope is that it will point the way towards a more integrated approach to these challenges and towards water and energy solutions that work for all the world's people.

Ki Moon Ban

Ban Ki-moon

FOREWORD

by Irina Bokova
Director-General of UNESCO

The *World Water Development Report 2014* shines light on the interdependence between the management of water and energy. Thanks to its clarity and relevance, this important document reminds us that the linkages between freshwater and energy are crucial to human well-being and sustainable socio-economic development. Water is essential throughout the production, transportation and use of energy, which, in turn, affects the water cycle. This interdependence calls for an improved cooperation between all actors, given the importance of freshwater and energy for sustainable development.

Ensuring access to freshwater and energy for all, especially the poor and most disadvantaged, is our key challenge. The fundamental right to freshwater is not exercised by some 3.5 billion women and men – who often also lack access to reliable energy, especially electricity. As the 2013 International Year for Water Cooperation showed, there is enough water on earth – we need to manage it better together.

This challenge is becoming steeper as demands increase, especially in emerging economies, where agriculture, industry and urban development are evolving quickly. We must find sustainable ways to ensure access to quality freshwater and energy for all.

Rising pressure on resources calls for new production and consumption models. We need to better understand the connections between water and energy, because choices made in one area impact – positively or negatively – the other. Every production model in energy has consequences on the quantity and quality of available water. In the past, these resources were managed by competition. In the future, we must choose cooperation, and make choices to craft just compromises for all. Public policies have a key role to play in mobilizing and in directing change, and, for this, they must draw on reliable data and strong scientific research.

This Report depicts the complexity of challenges and provides directions to guide decision-makers in tackling them. Clearly, technical solutions will not be enough to address stakes that are, above all, political, economic and educational. Education for sustainable development is essential to help new generations create win–win equations for water and energy. Private sector engagement and government support to research and development are crucial for the development of renewable – and less water intensive – energy sources.

Looking to the future, this Report shows the unequal weight of each sector. Energy has always been seen as ‘big business’ compared to water, benefitting from strategic investment, while water remains still too often perceived as a ‘gift of nature’, as a public good and human right. Currently, 90% of energy production relies on intensive and non-reusable water models that are not sustainable. Sustainability calls on us to bridge human rights and dignity with economic and social growth, and this must start with getting right the interdependence between energy and water.

As the intellectual agency of the United Nations, UNESCO is bringing its mandate and experience to help reach this goal. From now on a comprehensive report will be published every year, on a specific theme, and I wish to highlight the scale of work mobilized to produce this one. It draws on the joint efforts of all members of UN-Water and our partners. I am convinced that this Report will make a unique contribution to shaping a new post-2015 sustainable development agenda, and I call on all readers, professional and general, to share its messages as widely as possible.

Irina Bokova

Irina Bokova

FOREWORD

by Michel Jarraud
Chair of UN-Water and Secretary-General of WMO

In my capacity as Chair of UN-Water, I am pleased to present this year's edition of the World Water Development Report (WWDR).

As the reference publication of the UN system on the status of the freshwater resource, the WWDR is a praiseworthy example of the UN system working and delivering as one. Indeed, the Report is a flagship publication of UN-Water – the UN inter-agency coordination mechanism on all freshwater-related issues, including sanitation – and the 31 UN-Water Members and 36 other international Partners have worked together to deliver the coherent and integrated response of the UN system to freshwater-related issues and emerging challenges.

The WWDR 2014 is the fifth report in the series and it marks a milestone as the first annual edition. The WWDR was originally a triennial report which provided an overall picture of the state, uses and management of the world's freshwater resources. In late 2011 and early 2012, an extensive survey was carried out to assess the expectations on the Report and the needs of the global community. The consensus from the immense number of responses from all parts of the world indicated that an annual, factual and more concise publication with a specific thematic focus was needed. The structure of the Report was therefore redesigned and it is UN-Water's hope that the findings and conclusions will serve to provide a broad public – from politicians and decision-makers to practitioners – with the latest information and examples of how water-related challenges are addressed around the world.

In addition to this, starting from this year 2014, the theme of the WWDR and that of World Water Day will be harmonized to provide a deeper focus and an enhanced attention. This harmony, by design, will help putting the important World Water Day topics high on the international agenda. In this year's edition, the WWDR highlights that water and energy are highly interdependent and lie at the core of sustainable development. It is clear that choices made in one domain can have significant impacts on the other – with both positive and negative repercussions. Increasing demand for freshwater and energy over the coming decades will greatly amplify existing challenges worldwide. This calls for innovative and pragmatic policies prioritizing more efficient and cost effective management of water and energy services in an integrated way.

I highly commend all my UN-Water colleagues who took active part in development of this Report. I would also like to express my profound appreciation to the UN Educational, Scientific and Cultural Organization (UNESCO) for hosting the World Water Assessment Programme (WWAP), which has been coordinating the production and publication of the UN-Water WWDR. Finally, I would also like to thank the Government of Italy for its commitment and support to WWAP.

I sincerely believe that the findings and messages presented in this Report will inform the discussions around the Post-2015 Development Agenda and help the international community commit to poverty eradication and sustainable development beyond 2015.

Michel Jarraud

PREFACE

by Michela Miletto, WWAP Coordinator a.i.
and Richard Connor, WWDR 2014 Lead Author

As the first of a new series of theme-oriented reports to be released on an annual basis, this fifth edition of the United Nations *World Water Development Report* (WWDR) marks a pivotal new direction for the WWDR series, the World Water Assessment Programme (WWAP), and the many partner agencies that work with us in the production of the flagship report of UN-Water.

In preparing this report, we quickly became quite amazed at just how deep the interlinkages between water and energy actually run. The interconnections do not boil down to a handful of issues such as hydropower, biofuels and pumping groundwater for irrigation. The fact is that nearly all forms of energy production require a certain amount of water – in some cases a very large amount – which has critical implications for water resources, and by extension to other users and the environment. Furthermore, the most pressing water-related challenges often have a significant energy component, which can be a positive or a negative determining factor in the provision of water-related services to people and industry.

The complex and sometimes veiled interlinkages between water and energy are presented using the most recent data and information available at the time the Report was prepared. This proved to be a challenge on its own given that there is no official repository for statistics pertaining to both water and energy. For example, it proved quite difficult to obtain and compare data on several water and energy metrics over a single recent year, and the time horizons for water and energy demand projections, or infrastructure financing requirements, do not always overlap. Nonetheless, the Report's Data and Indicators Annex offers a wealth of complementary quantitative information that we hope will contribute to meeting the need for a compendium of water and energy related data. The Report also provides decision-makers and practitioners with specific examples of measures, actions and approaches to addressing interconnected challenges, ranging from issues of sustainable resource management financing to the efficiency of service delivery. Many of these are further detailed in the case studies found in Volume 2.

Like its predecessors, the WWDR 2014 is primarily targeted at national level decision-makers and water resources managers. However, it is hoped the Report will also be well received by academics, the energy community and the broader developmental community as well by those who, as described throughout the Report, play key roles in determining our common water future in an era when the need to produce ever increasing amounts of energy, and in particular clean energy, has become one of the greatest challenges to humankind.

This latest edition of the WWDR is the result of a concerted effort between WWAP, the five lead agencies (FAO, UNEP, UN-Habitat, UNIDO and the World Bank) responsible for the thematic part of the report, and the five United Nations regional commissions (UNECA, UNECE, UNECLAC, UNESCAP, UNESCWA) who provided a geographically focused perspective of the water and energy challenge.

The Report has also benefited to a great extent from the inputs and contributions of several UN-Water Members and Partners, as well as from dozens of scientists, professionals and non-governmental organizations who provided a variety of excellent material. The members of WWAP's Technical Advisory Committee were particularly active and generous in providing their guidance and knowledge to the production team. In line with WWAP's publications strategy, the Report is gender-mainstreamed thanks to the support of UN Women, WWAP's Advisory Group on Gender, and the UNESCO Division for Gender Equality. It has to be noted, however, that an in depth analysis of gender, water and energy interconnections will be possible only when gender-disaggregated data are widely available.

Water and energy meet at a crossroads where views and opinions can vary. We have endeavoured to present a fact-based, balanced and neutral report that presents the current state of knowledge and covers the most recent developments pertaining to water and energy. As we move towards a new paradigm of sustainable development, whether via a new set of development goals, the decoupling of water and economic growth or the 'greening' of economies, it is our sincere hope that all parties to the current and forthcoming debates concerning water and energy will find this factual report to be a useful, informative and credible tool which can serve as the knowledge base for open, transparent discussions pertaining to our common future.

On behalf of the staff of WWAP, we extend our deepest appreciation to the UN-Water lead agencies and regional commissions, to the Members and Partners of UN-Water, and to the authors, writers, editors and other contributors in producing this unique and authoritative report.

A particular thanks goes to Ms Irina Bokova, Director-General of UNESCO, for her critical support for WWAP and the production of the WWDR.

We deeply appreciate the Italian Government for funding the Programme and the Umbria Region for hosting the WWAP Secretariat in the prestigious premises of Villa La Colombella in Perugia. Their contribution has been instrumental for the production of the Report.

We extend our most sincere gratitude to all our colleagues of the WWAP Secretariat, whose names are listed in the Acknowledgements. Without them the Report would not have been completed. A special thanks goes to Alice Franek for her outstanding contributions in editing, design and coordination of the publication process, and to Simone Grego for his excellent work in coordinating the overall process.

Last but not least, special recognition goes to Olcay Ünver, who was WWAP Coordinator from 2007 to September 2013, and who played a key role in the design and development of this report up to his very last day in the office.

Michela Miletto **Richard Connor**

ACKNOWLEDGEMENTS

This report would not have been possible without the essential and varied contribution of many organizations, institutions and individuals around the world.

The generous financial support from the Italian Government as well as the premises made available by the Umbria Region has been instrumental for the preparation of this report.

We would like to express our gratitude to the Director-General of UNESCO, Ms Irina Bokova, for her crucial support for the United Nations World Water Assessment Programme (WWAP).

Special thanks go to the higher management of the UNESCO Natural Sciences Sector, and in particular to Ms Blanca Jiménez Cisneros, Director of the Division of Water Sciences and Secretary of the International Hydrological Programme (IHP), and the professionals and general staff of the Division for their support and assistance.

We wish to thank UN-Water Members and Partners for their contributions, intellectual guidance, useful revisions and timely endorsements. Special thanks go to UNIDO for hosting the WWDR 2014 developmental workshop.

We acknowledge the guidance and valuable contributions provided by David Coates, Alan Hall and Jack Moss, and thank the Global Water Partnership (GWP), the World Water Council, and the International Groundwater Resources Assessment Centre (IGRAC) for their support.

A special acknowledgement goes to all of the case study partners who volunteered their efforts, without which Volume 2 would not be complete.

We extend our gratitude to all the individuals who provided comments on drafts of the report, and to their host institutions for allowing them to do so.

Finally, we wish to thank Olcay Ünver, WWAP Coordinator until September 2013.

All those whom we have inadvertently omitted from the list please accept our sincere apologies along with our thanks.

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EXECUTIVE SUMMARY

Water and energy are tightly interlinked and highly interdependent. Choices made in one domain have direct and indirect consequences on the other, positive or negative. The form of energy production being pursued determines the amount of water required to produce that energy. At the same time, the availability and allocation of freshwater resources determine how much (or how little) water can be secured for energy production. Decisions made for water use and management and for energy production can have significant, multifaceted and broad-reaching impacts on each other – and these impacts often carry a mix of both positive and negative repercussions.

The challenge today: Extending services to the unserved

Freshwater and energy are crucial for human well-being and sustainable socio-economic development. Their essential roles in achieving progress under every category of development goal are now widely recognized. Major regional and global crises – of climate, poverty, hunger, health and finance – that threaten the livelihood of many, especially the three billion people living on less than US$2.50 per day, are interconnected through water and energy.

Worldwide, an estimated 768 million people remain without access to an improved source of water – although by some estimates, the number of people whose right to water is not satisfied could be as high as 3.5 billion – and 2.5 billion remain without access to improved sanitation. More than 1.3 billion people still lack access to electricity, and roughly 2.6 billion use solid fuels (mainly biomass) for cooking. The fact that these figures are often representative of the same people is evidenced by a close association between respiratory diseases caused by indoor air pollution, and diarrhoea and related waterborne diseases caused by a lack of safe drinking water and sanitation.

The challenge to come: Meeting growing demands

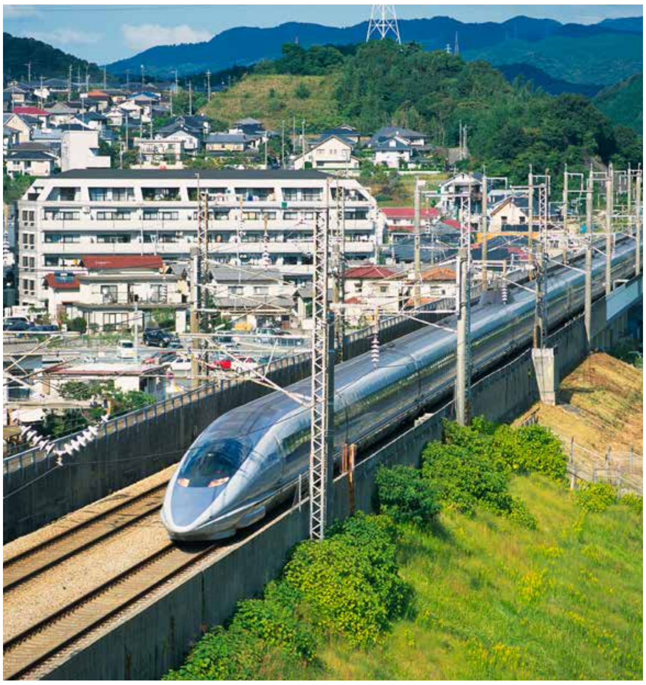
Demands for freshwater and energy will continue to increase significantly over the coming decades to meet the needs of growing populations and economies, changing lifestyles and evolving consumption patterns, greatly amplifying existing pressures on limited natural resources and on ecosystems. The resulting challenges will be most acute in countries undergoing accelerated transformation and rapid economic growth, or those in which a large segment of the population lacks access to modern services.

Global water demand (in terms of water withdrawals) is projected to increase by some 55% by 2050, mainly because of growing demands from manufacturing (400%), thermal electricity generation (140%) and domestic use (130%). As a result, freshwater availability will be increasingly strained over this time period, and more than 40% of the global population is projected to be living in areas of severe water stress through 2050. There is clear evidence that groundwater supplies are diminishing, with an estimated 20% of the world's aquifers being over-exploited, some critically so. Deterioration of wetlands worldwide is reducing the capacity of ecosystems to purify water.

Global energy demand is expected to grow by more than one-third over the period to 2035, with China, India and the Middle Eastern countries accounting for about 60% of the increase. Electricity demand is expected to grow by approximately 70% by 2035. This growth will be almost entirely in non-Organisation for Economic Co-operation and Development countries, with India and China accounting for more than half that growth.

What rising energy demand means for water

Energy comes in different forms and can be produced in several ways, each having a distinct requirement for – and impact on – water resources. Thus, as a country's or region's energy mix evolves, from fossil fuels to renewables for example, so too do the implications on water and its supporting ecosystem services evolve. Approximately 90% of global power generation is water intensive.



The International Energy Agency estimated global water withdrawals for energy production in 2010 at 583 billion m^3 (representing some 15% of the world's total withdrawals), of which 66 billion m^3 was consumed. By 2035, withdrawals could increase by 20% and consumption by 85%, driven via a shift towards higher efficiency power plants with more advanced cooling systems (that reduce water withdrawals but increase consumption) and increased production of biofuel. Local and regional impacts of biofuels could be substantial, as their production is among the most water intensive types of fuel production.

Despite ongoing progress in the development of renewables, the overall evolution of the global energy mix appears to remain on a relatively fixed path: that of continued reliance on fossil fuels. Oil and gas extraction yields high volumes of 'produced water', which comes out of the well along with the oil and gas. Produced water is usually very difficult and expensive to treat. Unconventional oil and gas production is generally more water intensive than conventional oil and gas production.

Thermal power plants are responsible for roughly 80% of global electricity production, and as a sector they are a large user of water. Power plant cooling is responsible for 43% of total freshwater withdrawals in Europe (more than 50% in several countries), nearly 50% in the United States of America, and more than 10% of the national water cap in China.

Similarities, differences and divergences: Beyond the water–energy nexus

The decisions that determine how water resources are used (or abused) stem from broader policy circles concerned primarily with industrial and economic development, public health, investment and financing, food security and, most relevant to this report, energy security. The challenge for twenty-first century governance is to embrace the multiple aspects, roles and benefits of water, and to place water at the heart of decision-making in all water-dependent sectors, including energy.

Energy is big business compared to water and can command a great many more resources of all kinds. Market forces have tended to play a much more important role in energy sector development compared with the management of water resources and the improvement of water-related services (water supply and sanitation), which have historically been more of a public health and welfare issue. Water resources have been considered by some to be a *public good* (though the economic definition of 'public good' does not apply to freshwater) – with access to safe water and sanitation recognized as a *human right*. Neither concept ordinarily applies to energy. Reflecting this economic, commercial and social disparity, energy attracts greater political attention than water in most countries.

Growing demand for limited water supplies places increasing pressure on water intensive energy producers to seek alternative approaches, especially in areas where energy is competing with other major water users (agriculture, manufacturing, drinking water and sanitation services for cities) and where water uses may be restricted to maintain healthy ecosystems. Uncertainties related to the growth and evolution of global energy production, for example via growth in unconventional sources of gas and oil or in biofuels, can pose significant risks to water resources and other users. Policies that benefit one domain can translate to increased risks and detrimental effects in another, but they can also generate co-benefits. The need to manage trade-offs and maximize co-benefits across multiple sectors has become an urgent and a critical issue.

Water planners and decision-makers involved in assessing the water needs of the energy sector require a suitable level of knowledge about electricity generation and fuel extraction technologies and their potential impact on the resource. Energy planners and investors must take into account the complexities of the hydrological cycle and competing water uses when assessing plans and investments.

Thematic challenges and responses

There are many opportunities for the joint development and management of *water and energy infrastructure and technologies* that maximize co-benefits and minimize negative trade-offs. An array of opportunities exists to co-produce energy and water services and to exploit the benefits of synergies, such as combined power and desalination plants, combined heat and power plants, using alternative water sources for thermal power plant cooling, and even energy recovery from sewerage water. Besides the pursuit of new technical solutions, new political and economic frameworks need to be designed to promote cooperation and integrated planning among sectors. Innovative approaches to spending efficiency, such as cross-sector cooperation to leverage possible synergies, integrated planning for water and energy to decrease costs and ensure sustainability, assessing trade-offs at the national level, demand-side interventions, and decentralized services, can help overcome the infrastructure financing gap which, although significant for energy, is far greater for water.

In the context of *thermal power generation*, there is an increasing potential for serious conflict between power, other water users and environmental considerations. Trade-offs can sometimes be reduced by technological advances, but these advances may carry trade-offs of their own. From a water perspective, solar photovoltaic and wind are clearly the most sustainable sources for power generation. However, in most cases, the intermittent service provided by solar photovoltaic and wind needs to be compensated for by other sources of power which, with the exception of geothermal, *do* require water to maintain load balances. Support for the development of renewable energy, which remains far below that for fossil fuels, will need to increase dramatically before it makes a significant change in the global energy mix, and by association, in water demand. Use of geothermal energy for power generation is underdeveloped and its potential is greatly underappreciated. It is climate independent, produces minimal or near-zero greenhouse gas emissions, does not consume water, and its availability is infinite at human time scales.

Agriculture is currently the largest user of water at the global level, accounting for some 70% of total withdrawals. The food production and supply chain accounts for about one-third of total global energy consumption. The demand for agricultural feedstocks for biofuels is the largest source of new demand for agricultural production in decades,

and was a driving factor behind the 2007–2008 spike in world commodity prices. As biofuels also require water for their processing stages, the water requirements of biofuels produced from irrigated crops can be much larger than for fossil fuels. Energy subsidies allowing farmers to pump aquifers at unsustainable rates of extraction have led to the depletion of groundwater reserves. Applying energy efficiency measures at the farm and at all subsequent stages along the agrifood chain can bring direct savings, through technological and behavioural changes, or indirect savings, through co-benefits derived from the adoption of agro-ecological farming practices. Knowledge-based precision irrigation can provide flexible, reliable and efficient water application, which can be complemented by deficit irrigation and wastewater reuse.

Many *rapidly growing* cities in developing countries already face problems related to water and energy and have limited capacity to respond. As energy cost is usually the greatest expenditure for water and wastewater utilities, audits to identify and reduce water and energy losses and enhance efficiency can result in substantial energy and financial savings. The future water and energy consumption of a new or an expanding city can be reduced during the early stages of urban planning through the development of compact settlements and investment in systems for integrated urban water management. Such systems and practices include the conservation of water sources, the use of multiple water sources – including rainwater harvesting, stormwater management and wastewater reuse – and the treatment of water to the quality needed for its use rather than treating all water to a potable standard. The chemically bound energy in wastewater can be used for domestic cooking and heating, as fuel for vehicles and power plants, or for operating the treatment plant itself. This biogas replaces fossil fuels, reduces the amount of sludge to be disposed of and achieves financial savings for the plant.

Industry seeks both water and energy efficiency though the two are not always compatible, and though a programme of water and energy efficiency can diverge from industry's primary focus: to secure water and energy at the lowest prices. Individually and together water and energy efficiency involve varied trade-offs, which frequently involve short-term cost increases against long-term savings, the balance between water and energy use, and a compromise with other factors such as labour, transportation, raw material costs and market location. Large companies and multinationals, particularly in the food and beverage sector, have been engaged for some time in improving water and energy efficiencies. Such companies see the value of efficiencies in both monetary and societal terms. Small and medium-sized enterprises (with 20 or fewer employees) comprise more than 70% of enterprises in most economies, and although as a group they have the potential for making a significant impact on water and energy efficiencies, they have fewer resources and are commonly in need of equity capital to do so.

The availability of adequate quantities of water, of sufficient quality, depends on *healthy ecosystems* and can be considered an ecosystem service. The maintenance of environmental flows enables this and other ecosystem services that are fundamental to sustainable economic growth and human well-being. Ecosystem services are being compromised worldwide, and energy production is one of the drivers of this process. Natural or green infrastructure can complement, augment or replace the services provided by traditional engineered infrastructure, creating additional benefits in terms of cost-effectiveness, risk management and sustainable development overall. The economic value of ecosystems for downstream water users is formally recognized and monetized in payments for environmental services schemes, in which downstream users provide farmers with payments or green water credits for good management practices that support and regulate ecosystem services, thereby conserving water and preserving its availability and quality.

Regional priorities

The expansion of hydropower as a key source of renewable energy is a critical issue across nearly all of the world's regions due to concerns of growing conflicts between various interests over limited water resources.
In *Europe and North America*, water scarcity, hydrological variability and the impacts of climate change on water availability and energy production are increasingly recognized as critical – and related – issues. Targets set to increase the share of renewable energies have led to renewed interest in developing pumped storage while part of the region – notably Central Asia and South-Eastern Europe – are still developing new hydropower capacity, not always compatibly with other water uses. Uncertainties persist over the potential risks to water quality, human health and long-term environmental sustainability from the development of unconventional sources of gas ('fracking') and oil ('tar sands'), both of which require large quantities of water.

With its demand for energy increasing exponentially, the *Asia-Pacific* region faces major supply challenges. Coal, the most prevalent energy product within the region, will continue to be the main source of energy, despite serious concerns about water quality degradation as an effect of coal mining and the water quantity required for cooling thermal power plants. The potential for Asia to develop into a significant market for and exporter of biofuels is being increasingly recognized, and there is a hope that it will provide new employment opportunities in several developing nations.

In the *Arab region*, the low to middle income countries are struggling to meet growing demands for water and energy services. Limited understanding of the interdependencies affecting the management of water and energy resources has stymied coordination between water and energy policy-makers, and limited coordination between the water, energy, electricity and agriculture sectors has led to conflicting policies and development objectives. Solar-driven desalination and energy recovery from wastewater are two promising technologies particularly well suited to the region.

In *Latin America and the Caribbean*, there is an increasing interest in biofuels and in how more water efficient (and more energy intensive) irrigation methods and electricity subsidies to farmers impact on aquifer sustainability. The vast majority of water utilities in the region are struggling to attain self-financing and, as energy is often the greatest component (30–40%) of operational costs, increasing energy costs have direct implications for service affordability and for sector financing.

The majority of the rural population in *sub-Saharan Africa* relies on traditional energy supplies, mainly unprocessed biomass, the burning of which causes significant pollution and health concerns. It is the only region in the world where the absolute number of people without access to electricity is increasing. As Africa has not yet tapped in to its rich potential for hydropower development to a substantial degree, it has the opportunity of learning from the positive as well as the negative aspects of hydropower implementation practices that other nations have undergone.

Enabling environments

Recognition of the interconnectedness between water and energy has led some observers to call for a greater level of integration of the two domains. Although this may be possible and beneficial under certain circumstances, an increased level of collaboration and coordination would create favourable outcomes in nearly all situations. Effective collaboration does not necessarily require that responsibilities for water and energy are combined into the same institutional portfolio, nor does doing so assure coherent cooperation.

Water and energy practitioners need to engage with and fully understand one another. Both domains have been traditionally expected to focus on a narrow mandate in meeting their own aims and fulfilling their own targeted responsibilities. There is often little or no incentive to initiate and pursue coordination or integration of policies across sectoral institutions. Policy-makers, planners and practitioners in water and energy need to take steps to identify and overcome the barriers that exist between their domains.

The most common responses to the dilemmas, risks and opportunities presented in this fifth edition of the United Nations *World Water Development Report* are related to improving the efficiency and sustainability with which water and energy are used and finding win–win options that create savings of both, which can become mutually reinforcing (creating synergy). But not every situation offers such opportunities. There are situations in which competition for resources can arise or there is genuine conflict between water and energy aims, meaning some degree of trade-off will be necessary. Dealing with trade-offs may require and benefit from negotiation, especially where international issues are involved. Where competition between different resource domains is likely to increase, the requirement to make deliberate trade-offs arises and these trade-offs will need to be managed and contained, preferably through collaboration and in a coordinated manner. To do this, better (and sometimes new) data are required.

The incentives to increase efficiency facing the two domains are asymmetrical: energy users have little or no incentive to conserve water due to zero or low prices, but water users normally do pay for energy, even though prices may be subsidized. Water and energy prices are strongly affected by political decisions and subsidies that support major sectors such as agriculture and industry, and these subsidies often distort the true economic relationship between water and energy. Particularly for water, price is rarely a true reflection of cost – it is often even less than the cost of supply.

A coherent policy – which is to say an adequate public response to the interconnectedness of the water, energy and related domains – requires a hierarchy of actions. These include:

- Developing coherent national policies affecting the different domains
- Creating legal and institutional frameworks to promote this coherence
- Ensuring reliable data and statistics to make and monitor decisions
- Encouraging awareness through education, training and public information media
- Supporting innovation and research into technological development
- Ensuring availability of finance
- Allowing markets and businesses to develop

Together these actions make up the *enabling environment* necessary to bring about the changes needed for the sustainable and mutually compatible development of water and energy. The international community can bring actors together and catalyse support for national, subnational and local governments as well as utility providers, who have a major role in how the water–energy nexus plays out at the national and local levels.

The different political economies of water and energy should be recognized, as these affect the scope, speed and direction of change in each domain. While energy generally carries great political clout, water most often does not. Partly as a result, there is a marked difference in the pace of change in the domains; a pace which is driven also by the evolution of markets and technologies. Unless those responsible for water step up their own governance reform efforts, the pressures emanating from developments in the energy sphere will become increasingly restrictive and make the tasks facing water planners, and the objective of a secure water future, much more difficult to achieve. And failures in water can lead directly to failures in energy and other sectors critical for development.

INTRODUCTION

Water and energy are closely interconnected and highly interdependent. Choices made and actions taken in one domain can greatly affect the other, positively or negatively. Trade-offs need to be managed to limit negative impacts and foster opportunities for synergy. Water and energy have crucial impacts on poverty alleviation both *directly*, as a number of the Millennium Development Goals (MDGs) depend on major improvements in access to water, sanitation, power and energy sources, and *indirectly*, as water and energy can be binding constraints on economic growth – the ultimate hope for widespread poverty reduction.

In view of the post-2015 Sustainable Development Goals, likely to include increased access to water and energy services, this fifth edition of the United Nations *World Water Development Report* seeks to inform decision-makers (inside and outside the water and energy domains), stakeholders and practitioners about the interlinkages, potential synergies and trade-offs, and to highlight the need for appropriate responses and regulatory frameworks that account for both water and energy priorities. The Report provides a comprehensive overview of major and emerging trends from around the world, with examples of how some of the trend-related challenges have been addressed, their implications for policy-makers, and further actions that can be taken by stakeholders and the international community.

Part 1 of the Report, 'Status, trends and challenges', explores current and future challenges of sustainable development in the context of ever-increasing demands for water and energy. Chapter 1 describes many of the complex interlinkages between the water and energy domains from varied perspectives, highlighting their interdependencies and differences, as well as their relationships to other developmental sectors. Chapter 2 focuses on water, examining current and future demand and the pressures that drive demand as well as the energy requirements for the provision of water services. The chapter also provides a snapshot of the state of water resources using the latest information available. Chapter 3 examines sources of energy, both renewable and non-renewable, and existing means of power generation in terms of their current and future contribution to the global energy mix and their impact on water. Chapter 4 focuses on data and knowledge issues directly related to the water–energy nexus, highlighting the need to generate and harmonize data concerning the supply and use of water and energy production.

In the future, growing demands on water resources resulting from population growth, economic development and urban expansion will create additional pressure on water intensive energy production. Climate change will add to the pressure. Droughts, heatwaves and local water scarcities of the past decade have interrupted electricity generation, with serious economic consequences. At the same time, limitations on energy availability have constrained the delivery of water services. Growing demand for finite water resources is also leading to increased competition between the energy sector and other water-using sectors of the economy, principally agriculture and industry. A very important aspect of the burgeoning global demand for water services is the resulting pressure on water resources and the degradation of freshwater ecosystems.

Part 2, the 'Thematic focus', narrows the examination of water and energy into five specific themes. Chapter 5 looks into the economic aspects of water and energy infrastructure in developed and developing countries, highlighting some opportunities for synergies in infrastructure development, operation and maintenance. The challenges and response options faced by food and agriculture, including biofuels, in relation to water and energy are presented in Chapter 6. Chapter 7 focuses on the particular difficulties facing the large and rapidly expanding cities in developing countries. Chapter 8 describes the role of industry as both a user of water and energy but also a potential leader in the development of innovative approaches to efficiency. Part 2 concludes with Chapter 9, which argues that ecosystems are the foundation of the water–energy nexus and that an ecosystem approach is vital for green growth.

'Regional aspects' of water and energy are provided in Part 3. Issues of concern for Europe and North America, from expanding hydropower and its related conflicts to the development of unconventional sources of oil and gas, are presented in Chapter 10. Chapter 11 describes how increasing reliance on coal and the development of biofuel in the Asia-Pacific region will impact on water resources and other users. The need to increase knowledge and raise awareness for policy coherence and the potential of certain water supply and treatment technologies in the Arab region are addressed in Chapter 12. Chapter 13 examines hydropower development and the energy requirements for water services in Latin America and the Caribbean. Hydropower is also the focus of Chapter 14, which highlights the urgent need to increase access to electricity in sub-Saharan Africa where the undeveloped potential for hydropower is the greatest of any region.

Where competition between different resource domains is likely to increase, the requirement to make deliberate trade-offs arises, and these trade-offs will need to be managed and contained, preferably through collaboration and in a coordinated manner. There are, fortunately, already good examples of policies and actions that benefit both water and energy domains, such as win–win projects and optimized trade-offs.

Part 4, 'Responses: Fostering synergies and managing trade-offs', describes how policy-makers, decision-makers and practitioners can respond to the dilemmas, risks and opportunities presented in the first three parts of the Report. Chapter 15 proposes a hierarchy of actions that together make up the enabling environment necessary to bring about the changes needed for the sustainable and mutually compatible development of water and energy. These actions include overcoming the barriers that exist between the two domains, using economic instruments appropriately, and optimizing the role of the United Nations system and the international community. The Report concludes with Chapter 16, in which the interplay of water and energy, and the scope for fostering synergies and managing trade-offs between them, is illustrated in the contexts of agriculture, industry, cities, ecosystems and power generation.

PART 1

STATUS, TRENDS AND CHALLENGES

CHAPTERS

1. The water–energy nexus
2. Water: Demands, energy requirements and availability
3. Energy's thirst for water
4. Data challenges and opportunities

CHAPTER 1

The water–energy nexus

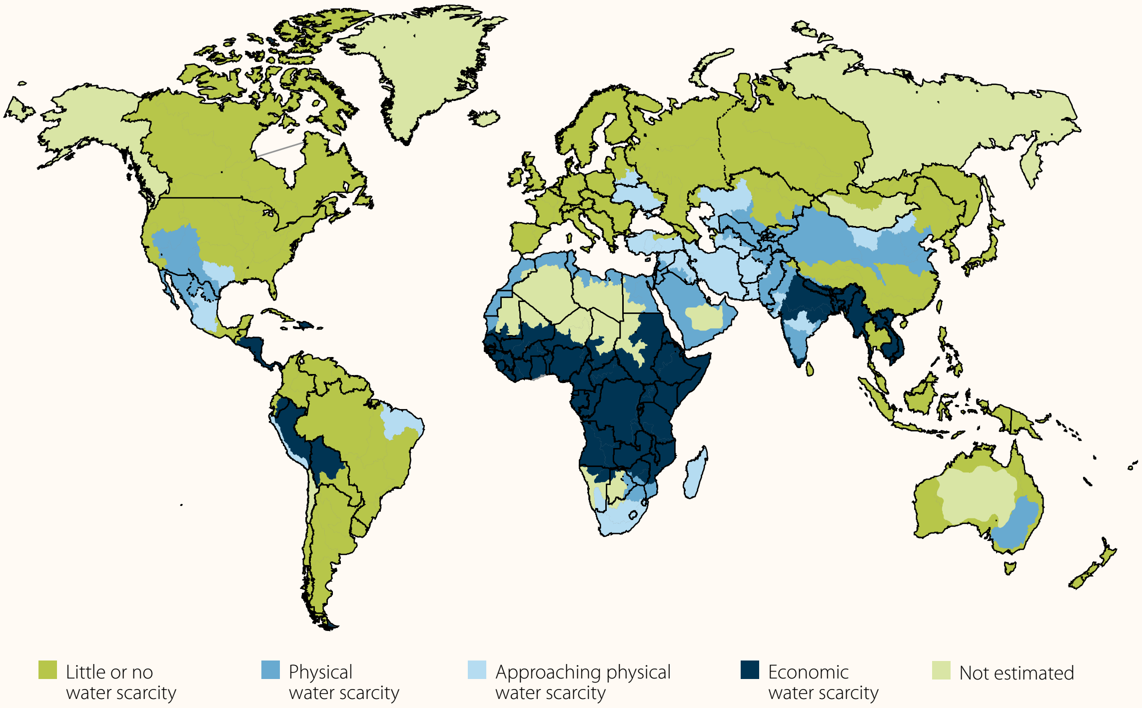
WWAP | Richard Connor and James Winpenny

Freshwater and energy are critical to human well-being and sustainable socio-economic development. Although initially overlooked by many, their essential roles in achieving progress towards every one of the MDGs are now widely recognized. Globally, demand for freshwater and energy will continue to increase significantly over the coming decades to meet the needs of increasing populations, growing economies, changing lifestyles and evolving consumption patterns. This will greatly amplify pressures on limited natural resources and ecosystems. The challenge will be most acute in countries undergoing accelerated transformation and rapid economic growth, especially where water resources are scarce or where water-related infrastructure and services are inadequate (Figure 1.1), and where modern energy services remain largely underdeveloped (Figure 1.2).

Water and energy are strongly interlinked: water is required to produce, transport and use all forms of energy to some degree; and energy is required for the extraction, treatment and distribution of water, as well as its collection and treatment after use. Water and energy

FIGURE 1.1

Global physical and economic surface water scarcity



Definitions and indicators

- Little or no water scarcity. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- Physical water scarcity (water resources development is approaching or has exceeded sustainable limits). More than 75% of river flows are withdrawn for agriculture, industry and domestic purposes (accounting for recycling of return flows). This definition – relating water availability to water demand – implies that dry areas are not necessarily water scarce.
- Approaching physical water scarcity. More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- Economic water scarcity (human, institutional and financial capital limit access to water even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Source: Comprehensive Assessment of Water Management in Agriculture (2007, map 2, p. 11). © IWMI, used under licence.

are also highly interdependent, with choices made in one domain having direct and indirect consequences on the other. The quantities of water required to produce energy are determined by the forms of energy production pursued; the allocation, use and management of freshwater resources can determine how much (or little) water is available for energy production. The choices made for water and energy can also impact other sectors, and vice versa. These interlinkages and interdependencies, along with their negative and positive externalities, lie at the heart of what has become known as the 'water–energy nexus'.

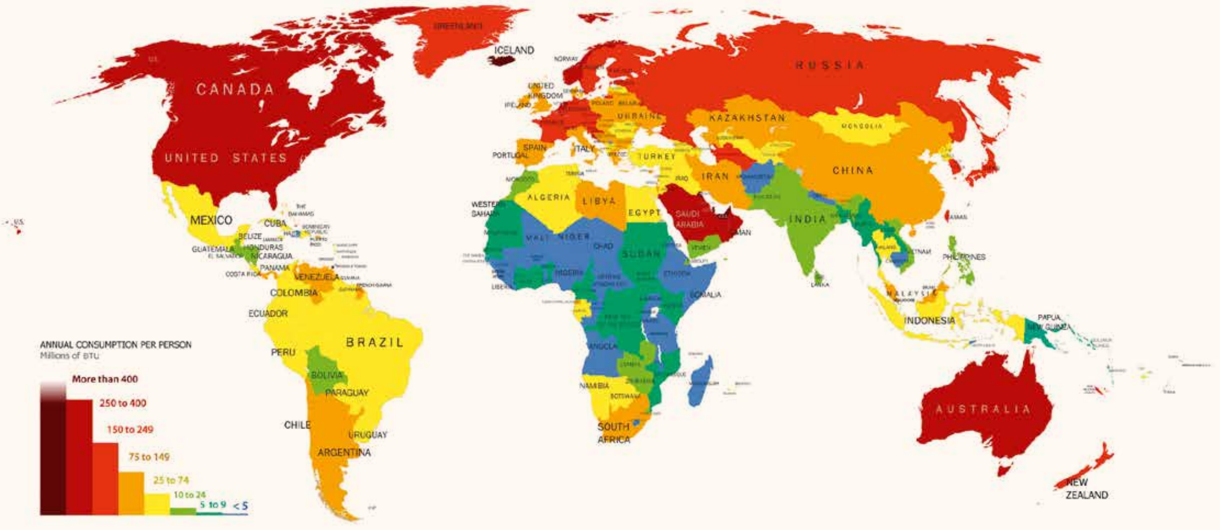
Major regional and global crises – climate, food, energy, financial – threatening the livelihood of many, including the three billion people living on less than US$2.50 per day, are interlinked through the water–energy nexus. The case of access to basic water and energy services illustrates this point. The same people who lack access to improved water and sanitation are also likely to lack access to electricity and rely on solid fuel for cooking (Table 1.1). Women and children represent a disproportional fraction of the unserved and underserved.

Many people in the world still lack access to basic water and energy services. A 2013 report by WHO and UNICEF concluded that 768 million remain without access to an improved source of water and 2.5 billion people remain without access to improved sanitation, respectively (WHO/UNICEF, 2013*a*). The High-level Panel on the Post-2015 Development Agenda has indicated that 2 billion people do not have access to safe water (UN, 2013). The number of people whose right to water is not satisfied is even greater, probably in the order of 3.5 billion (Onda et al., 2012).

More than 1.3 billion people worldwide still lack access to electricity, with more than 95% of them located in sub-Saharan Africa and developing Asia, and roughly 2.6 billion people rely on the traditional use of biomass for cooking (IEA, 2012*a*). Another estimated 400 million people rely on coal for cooking and heating purposes, which, like wood, charcoal, peat or other biomass, causes air pollution and has serious potential health implications when used in traditional stoves. It is no coincidence that the figures concerning access to water services and energy align so well; it is often the same people who are missing out on both. The close association between respiratory diseases caused by indoor air pollution and waterborne diseases like diarrhoea caused by lack of safe drinking water and sanitation is a point of evidence for this.

Decisions made for water use and management and the production of energy can have significant, multifaceted

FIGURE 1.2 **Energy consumption per capita by country, 2010**



Note: BTU, British Thermal Unit. One million BTU approximately equals the energy derived from 30 litres of petrol.
Source: Burn: An Energy Journal (http://burnanenergyjournal.com/wp-content/uploads/2013/03/WorldMap_EnergyConsumptionPerCapita2010_v4_BargraphKey.jpg, from sources cited therein) (Accessed Oct 2013). Produced by Anrica Deb for SoundVision Productions®, used with permission.

and broad-reaching impacts on each other – often with a mix of both positive and negative repercussions. For example, drought exacerbates energy crises; energy price volatility contributes to food crises; the expansion of irrigation networks increases water and energy demand; and access to unreasonably inexpensive supplies of energy can lead to the depletion of water resources, further intensifying the impacts of droughts. Although integrated water resources management (IWRM) and the water–energy nexus have led to a growing recognition of such interdependencies, the complex direct and indirect interactions of this relationship are rarely fully appreciated, let alone incorporated into decision-making processes.

TABLE 1.1

Population using solid fuel for cooking and without access to electricity, improved water and sanitation in a selection of countries

		Electricity (national)	**Water (national)**	**Sanitation (national)**	**Cooking fuel (national)**
	Population (2011)[a] (million)	Population without access to electricity (2011)[b] (%)	Population without access to improved water (2011)[a] (%)	Population without access to improved sanitation (2011)[a] (%)	Population using solid fuel for cooking[*, c] (%)
Africa					
Burkina Faso	17.0	86.9	20.0	82.0	93.0 (2007)
Cameroon	20.0	46.3	25.6	52.2	75.0 (2005)
DR Congo	67.8	91.0	53.8	69.3	95.0 (2007)
Ethiopia	84.7	76.7	51.0	79.3	95.0 (2005)
Ghana	25.0	28.0	13.7	86.5	83.0 (2008)
Kenya	41.6	80.8	39.1	70.6	82.0 (2006)
Malawi	15.4	93.0	16.3	47.1	99.0 (2005)
Nigeria	162.5	52.0	38.9	69.4	75.0 (2007)
Senegal	12.8	43.5	26.6	48.6	56.0 (2006)
South Africa	50.5	15.3	8.5	26.0	17.0 (2007)
Togo	6.2	73.5	41.0	88.6	98.0 (2005)
Uganda	34.5	85.4	25.2	65.0	96.0 (2006)
Asia					
Bangladesh	150.5	40.4	16.8	45.3	91.0 (2007)
Cambodia	14.3	66.0	32.9	66.9	92.0 (2005)
China	1 347.6	0.2	8.3	34.9	55.0 (2000)
India	1 241.5	24.7	8.4	64.9	57.0 (2006)
Indonesia	242.3	27.1	15.7	41.3	55.0 (2007)
Mongolia	2.8	11.8	14.7	47.0	77.0 (2005)
Myanmar	48.3	51.2	15.9	22.7	95.0 (2004)
Nepal	30.5	23.7	12.4	64.6	83.0 (2006)
Pakistan	176.7	31.4	8.6	52.6	67.0 (2006)
Sri Lanka	21.0	14.6	7.4	8.9	78.0 (2006)
Thailand	69.5	1.0	4.2	6.6	34.0 (2005)

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The decisions that determine how water resources are used (or abused) are not made by water managers alone, but stem from broader policy circles primarily concerned with food security, industrial and economic development, public health, financing and energy security, among others (WWAP, 2009, 2012). The challenge for twenty-first century governance is to take account of the multiple aspects and roles of water, and of the benefits derived from it, and to place water at the heart of decision-making. This report addresses this challenge by probing into the complex inter-relationships between water, energy and development, and by describing strategies and approaches to managing trade-offs and maximizing the benefits for the betterment of all.

1.1 Interlocking risks and uncertainties

Risks to water resources lead to energy risks. Growing demand for limited water supplies increases pressure on water intensive energy producers to seek alternative approaches, especially in areas where energy is competing with other major water users (e.g. agriculture, manufacturing, drinking water and sanitation services for cities) and where water uses may be restricted to maintain healthy ecosystems. As growing water demand leads to increasing scarcity, it also leads to increasing urgency to manage trade-offs and maximize co-benefits across multiple sectors, including energy.

The power sector's dependence on water introduces vulnerabilities. Periods of water scarcity and elevated temperatures can force power plants to turn off or diminish their performance. As climate change induces

1.1 TABLE

Population using solid fuel for cooking and without access to electricity, improved water and sanitation in a selection of countries (continued from p. 14)

		Electricity (national)	**Water (national)**	**Sanitation (national)**	**Cooking fuel (national)**
	Population (2011)[a] (million)	Population without access to electricity (2011)[b] (%)	Population without access to improved water (2011)[a] (%)	Population without access to improved sanitation (2011)[a] (%)	Population using solid fuel for cooking[*,c] (%)
Latin America					
Argentina	40.8	2.8	0.8	3.7	5.0 (2001)
Bolivia	10.1	13.2	12.0	53.7	29.0 (2007)
Brazil	196.7	0.7	2.8	19.2	13.0 (2003)
Colombia	46.9	2.6	7.1	21.9	15.0 (2005)
Guatemala	14.8	18.1	6.2	19.8	62.0 (2003)
Haiti	10.1	72.1	36.0	73.9	94.0 (2005)
Nicaragua	5.9	22.3	15.0	47.9	57.0 (2006)
Peru	29.4	10.3	14.7	28.4	37.0 (2007)
Middle East					
Iraq	32.7	2.0	15.1	16.1	5.0 (2005)
Syrian Arab Republic	20.8	7.2	10.1	4.8	0.3 (2005)
Yemen	24.8	60.1	45.2	47.0	36.0 (2006)
World	**6 950.7**	**18.1**	**11.1**	**35.9**	**38.0 (2012) ****

*Note: * The reference year for the data is given in parentheses. ** Excludes coal.*

Source: Compiled by Engin Koncagül and Sisira Saddhamangala Withanachchi (WWAP), with data from [a] WHO/UNICEF (2013b, see http://www.wssinfo.org/data-estimates/table/); [b] OECD/IEA (World Energy Outlook 2013 Electricity Access Database at http://www.worldenergyoutlook.org/media/weowebsite/energydevelopment/WEO2013Electricitydatabase.xlsx); and [c] WHO Global Health Observatory Data Repository – Solid cooking fuels by country at http://apps.who.int/gho/data/node.main.136?lang=en.

more extreme weather events, the power sector might be exposed to higher levels of risk. Those impacts have already occurred in the energy sector globally, with many examples on all continents. Water constraints are among the determinants of where power plants are built and the choice of cooling systems. As water-related risks grow, these choices may become more limited and more critical. Conversely, projected climate change may also lower certain risks to electricity generation from hydropower in some areas (Hydro-Quebec, 2006; see also Section 13.1).

Equally, uncertainties related to the growth and evolution of global energy production can introduce new and significant risks to water resources and other users. The emergence of unconventional sources of gas and oil (e.g. shale gas and bitumen), recurrent concerns about nuclear power generation, and policy shifts towards renewable forms of energy will have significant implications on the state, demand for, use and management of freshwater resources (Box 1.1).

The response to growing energy demand can come at the expense of water resources sustainability, as in the case of shale oil and gas, biofuel and dewatering of aquifers to exploit coal seam gas, and vice versa desalination, expansion of pumped irrigation systems, or long-distance pumping of water for cities can increase energy needs. In terms of climate change mitigation, leading technologies for carbon capture and storage (CCS) are highly water intensive (Hussey et al., 2013).

Sustainability of water resources is becoming a business risk for some energy managers. Multinationals and other large corporations are increasingly interested in their water footprints and how to minimize them.[1] In its 2013 *Global Risks Report*, the World Economic Forum ranks the 'water supply crisis' as the fourth crisis in likelihood and second in impact, a marked elevation from its rank in previous reports (WEF, 2013).

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[1] For example, in the Water Footprint Network.

BOX 1.1

The evolution of the global energy mix and its implications for water

Global efforts to mitigate climate change and address energy security concerns, including the United Nations Secretary-General's 'Sustainable Energy for All' initiative (http://www.sustainableenergyforall.org), are driving the expansion of renewables in the aggregated global energy mix. Many nations have subscribed to this agenda with ambitious targets to double the share of renewables in the mix by 2030. Certain types of renewable energy, such as wind and solar photovoltaic (PV) power, have very low carbon footprints and consume little water. Other types of renewable energy, such as concentrated solar power and biofuels, can consume large quantities of water. Geothermal energy holds much promise in certain places but it remains grossly underdeveloped. Hydropower is in a class of its own because of the large quantities of water required to be stored and uncertainties regarding the amounts of water consumed as evaporative losses from reservoirs, not to mention hydropower's unique environmental and social impacts. Meeting ever-growing energy demands will require seeking coherence between water use and climate change mitigation.

In terms of electrical power generation, the intermittency of the two most rapidly expanding renewable sources, wind and solar PV, poses a challenge: How will secure load balances on larger grids be maintained against the backdrop of ever-increasing demand? Two options are currently more feasible and cost-effective than others: hydropower and thermal power (natural gas in particular). Both options have their advantages and disadvantages from water resource and climate change perspectives, as well as broader social, environmental and economic implications. Hydropower is arguably the best option in terms of energy storage and quick dispatch power required for counterbalancing the intermittency of other renewables. Yet, in several places, including the European Union, where nuclear power has come under disfavour and potential exists for expanding hydropower, tendencies are that these gaps are increasingly filled by (imported) natural gas. This trend is counterbalancing aspirations for energy security and self-sufficiency as well as climate change mitigation.

Sub-Saharan Africa, which has not yet tapped in to its rich potential for hydropower development to a substantial degree (Chapter 14) is in a prime position to benefit from the current drive towards renewable energy. Exploring the African potential of developing and enhancing regional power-pools, integrating grid networks, and enabling benefit sharing and trading to meet water and energy security and regional economic growth could also bring the add-on effects of increased peace and political and economic stability.

Source: Andreas Lindström, SIWI, and Richard Connor, WWAP.

1.2 Differences and divergences

In the simplest of terms, water is a renewable natural resource that is unique, irreplaceable and difficult (as well as costly) to move, beyond the pull of gravity. Energy, in contrast, comes in different forms, which can be derived from a variety of sources. It is typically a market-driven commodity and can be distributed across vast distances (e.g. via transmission lines for electricity or pipelines for fuels).

When considering water's role in the nexus, it is necessary to distinguish between water *resources* and water *services*, and how both are managed. *Water resources management* is about managing the water cycle, in which water flows as a natural resource through the environment (i.e. rivers, lakes, estuaries and other water bodies, soils and aquifers), in terms of quantity and quality. *Water services management* is about developing and managing infrastructure to capture, treat as necessary, transport and deliver water to the end user, and to capture the waste streams via reticulation for treatment and safe onwards discharge or reuse. Whereas energy is required mainly for the provision of water *services*, water *resources* are required in the production of energy.

Unlike water, energy can come in different forms and can be produced in several ways, each having a distinct requirement for – and impact on – water resources. Thus, as a country's or region's energy mix evolves, say from fossil fuels to renewables, so do the implications for water and its supporting ecosystem services.

In general, regulation and legislation regarding energy focuses on production and distribution, whereas for water the focus is mainly on extraction, use and discharge (Section 8.4.5). In most countries, approaches to energy decision-making and regulation are top-down, with strong national/federal or provincial/state governmental policies and central administration of many standards and funding. Water management is usually a combination of bottom-up and top-down approaches. National/federal water management can be responsible for managing large infrastructure such as major reservoir projects that serve as storage for irrigation and power generation as well as ensuring water allotments across international/interjurisdictional boundaries. However, the uses of that water are often determined locally, and local water management can be very powerful (for more on the governance of water, see WWAP, 2003 [ch. 15], 2006 [ch. 2], 2009 [chs. 14, 15], 2012 [pt. 2]). In most countries, local farmers make day-to-day decisions about well pumping for irrigation and national/federal control over water uses is weak, while centrally managed power systems are used for distributing electricity.

In addition to a mismatch in the regulatory and policy systems of water and energy, there is also a mismatch in the size of infrastructure. With the exception of large dams, reservoirs and inter-basin water diversion schemes, water infrastructure systems are usually at the community or city scale (for piped drinking water and sewerage systems). Energy infrastructure, including pipeline networks and the power grid, usually spans the entire nation or several nations. This mismatch can introduce vulnerabilities to both systems.

Water resources and water services systems span several geographic scales. While the piped water system is usually at the municipal scale, surface water can span thousands of kilometres, threading through many cities and crossing many political and national boundaries. The transboundary character of natural surface water systems complicates allocation decisions, as multiple government bodies might need to coordinate their actions across different regulatory frameworks and political systems. Because the original source of water might be far away, significant energy investments are typically required to deliver water resources and services to consumers. Groundwater can also span large regions, further complicating matters. In some regions, laws and international agreements governing groundwater (when they exist) can be different than those for surface water.

> ***Whereas energy is required** mainly for the provision of water* services, *water* resources *are required in the production of energy*

In contrast, the power grid and pipeline network does not follow natural boundaries such as river basins. Energy can be moved relatively easily: electricity is transmitted readily via power lines, and dense fossil fuels such as petroleum, coal and liquefied natural gas are shipped across oceans or transported across continents by pipelines or railways. While water can be moved via inter-basin transfer, because of water's high density and lower price points,[2] this approach requires significant investments of energy (Section 2.3) and is not economically feasible for bulk water.

In terms of infrastructure and operation, the most significant costs for energy services are related to capital investment in generating capacity and fuel. The cost for water provision is generally relatively low, but the risk arising from interruption of supplies can be significant. For water, the most significant costs are investment in networks and operation (including energy) and maintenance. In many critical installations the risk of energy supply interruption is also important, hence the existence of standby generation plants in many systems.

An additional challenge is that the water and energy communities have significantly different fundamental views and conceptual approaches. There is a need to create consistent frameworks for analysis, vocabularies and datasets that enable the two domains to understand each other and to communicate coherently with one another's decision-makers.

1.3 An economic comparison

The highly varied nature of both energy and water means that comparisons and differences have to be discussed at a high level of generality. The obvious similarities of networked urban supply in both do not mean that other aspects of the two domains can be treated alike. It is particularly important to differentiate water as a service and water as a resource, and similar considerations apply to energy as raw materials and as services (or primary and secondary energy). Also, the 'market for water services' should not be confused with 'water trading markets'[3] in the sense of trading rights to use raw water.

1.3.1 Economic similarities

Energy and water services are often (though by no means universally) structured as national, regional or local monopolies and are frequently publicly owned (though this is becoming less true of energy). Both energy and water have large fixed costs of supply in extraction, transmission and distribution, typically with heavy 'sunk costs' in facilities that have no alternative uses. These fixed costs form a large proportion of the total cost of supply. The 'marginal cost' of supplying extra units from existing capacity, particularly for networked services, is relatively low; conversely, the marginal cost of extra output once capacity is fully taken up is high, because new capacity has to be created. This implies that tariffs should (a) be flexible, reflecting the amount and timing of consumption; and (b) contain both fixed and variable elements, to ensure that fixed costs are covered whatever the level of demand.

For users not connected to a network, self-supply is necessary, frequently at a high cost compared to that of the public networked service. Thus there are large benefits from connection. However, the option of self-provision, whether for heat (wood), water (own sources), or sewerage and household sanitation, affects what the public supplier can charge. Large businesses and institutions have the economic resources to support options to provide their own services, which limits how much they can be asked to subsidize other users.

The recurrent operating costs of both water and energy comprise administrative overheads, labour, raw materials, power (in the case of water) and water (in the case of power and other forms of energy). In publicly owned utilities, administrative and labour costs tend to be proportionately higher than in privately owned utilities. In certain instances this may be due to political patronage, which inflates headcount and can impede reforms. Relatively high staff costs often leaves insufficient budget for materials, spare parts, electricity and other consumables. In Africa, and to varying degrees in other developing countries, maintenance is often insufficient or deferred, resulting in frequent outages, leakage and poor service. Power and water can have high levels of losses and inefficiency (AICD, 2012, for power p. 187, for water p. 309).

Due to the high public profile of both services there is often serious political interference with tariff setting, resulting in a high proportion of power and water utilities charging uneconomic tariffs (or failing to collect them) and posting financial losses. Farmers typically benefit from low charges for both power and irrigation water. Another way of describing this situation is that the energy and water domains both attract large perverse subsidies (Box 16.1), in the sense that they encourage greater consumption of natural resources that are, in different ways, scarce and costly (Komives et al., 2005).

The *operation of services* allows for involvement of the private sector to varying degrees in both energy and water, subject to regulation due to the monopoly element

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[2] Price points are prices at which demand for a given product is supposed to stay relatively high.

[3] Water trading is a voluntary exchange or transfer of a quantifiable water allocation between a willing buyer and seller.

in supply and the essential nature of the service. Private *ownership of infrastructure* entailed in public services is rarer than private operation of publicly owned assets. In both domains, public–private partnership (PPP) examples are increasing. In build-own-operate-transfer (BOOT) and build-operate-transfer (BOT) contracts, private concessionaires build and finance projects in the first instance, then operate them for the contract period to recoup outlays and earn a profit, and finally transfer the assets to public ownership. This is becoming a commonplace arrangement, mainly in wastewater treatment plants and independent power projects.

For both power and water, regulators are confronted with the conundrum of encouraging demand restraint in sectors where private companies earn their profits by expanding sales. There is interest in exploring ways of remunerating service providers according to their success in *reducing* demand, following use of this model in the California power sector as a substitute for linking rewards to expanding sales volumes (World Bank, 2010*a*).

1.3.2 Economic differences

The *scale* of the energy and water domains, measured in economic and commercial terms, differs widely. The global size of the water 'market' (for services, equipment and supplies) was estimated to be US$365 billion in 2005 and the market for water treatment and distribution plant and equipment for domestic and industrial use is currently (2013) valued at $557 billion (Goldman Sachs, 2005; GWI, 2013). Even allowing for market growth since this estimate, the annual global energy market (estimated at around $6 trillion[4]) dwarfs this sum: the International Energy Agency (IEA) (2012*a*) estimates that $37 trillion of investment will be needed over the period 2012–2035 in global energy supply infrastructure alone, equivalent to $1.6 trillion annually.

Energy dwarfs water not only in market size but in many other areas. The sheer sophistication and global girth of the energy supply chain lies in stark contrast to that of the water supply chain. The energy sector is synonymous with 'big business', and organization within the sector is well funded and represented (Hussey et al., 2013). Consistent with its economic and commercial scale, energy attracts greatly more political attention than water in most countries: as the Camdessus Report noted of water, 'some aspects of this sector are unglamorous, practically invisible in electoral terms' (Winpenny, 2003, p. 9).

Whereas energy is often managed nationally, water is managed regionally and locally. Decisions in water tend to be more highly delegated; water tariffs, for instance, are commonly decided at the municipal level. The level of private sector involvement also differs. While the drinking water and sanitation sector remains largely public, the involvement of private companies in the power sector remains at a relatively high level.

Access to safe water and sanitation is recognized as a *human right* (United Nations Resolution 64/292, 28 July 2010), neither of which generally applies to energy. Certain water, sanitation and hygiene (WASH) services are 'merit goods',[5] which may need active promotion (including subsidy) to convince users to take up what is on offer. Viewing water as a gift of nature (ignoring the economic cost of providing it as a service) impedes its economic pricing. No such attitude prevails in the markets for energy services.

Because of its low value-to-bulk ratio and high cost of transport, water is not commonly traded internationally or over long distances. Consequently water has no international price, unlike oil, while gas and coal are widely traded but with regional price differences, reflecting their transport and distribution systems. Although 'virtual water' – water embedded in goods and services – is implicitly traded on a large scale, the concept does not include any cost or price factorization and thus remains a theoretical tool with little economic influence. In a few countries, raw water (or the right to it) is traded in water markets on a seasonal or permanent basis, with prices subject to local supply and demand.

The sale of energy services (mainly electricity and some forms of heating) is predominately on a metered basis. In water services, metering is not nearly so widespread for households, and unusual for irrigation. The demand for household and industrial water is commonly considered to be 'price inelastic', where demand does not vary much with changes in price. The price elasticity of demand for irrigation water is less obvious, due to the very low price (often zero) charged for such water and the fact that this is often combined with subsidized energy for pumping (Molle and Berkoff, 2008). In contrast, the demand for

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[4] 'Energy is a $6 trillion global market', quote attributed to then US Commerce Secretary Gary Locke on a visit to China in May 2010 (Shirouzu, 2010).

[5] Those which governments supply to citizens as basic needs, which recipients may or may not be able or willing to pay for.

energy tends to have a higher price elasticity, making pricing a more cogent management instrument for this domain, as illustrated by the tariff differential between peak and off-peak consumption in certain countries. This implies that water tariff increases are likely to be more effective at raising revenues than in limiting demand.

BOX 1.2

Climate change adaptation and mitigation

Climate change adaptation is primarily about water, as stated for example by the Intergovernmental Panel on Climate Change (IPCC), which identifies water as the fundamental link through which climate change will impact humans and the environment (IPCC, 2008). In addition, water is critical for climate change mitigation, as many efforts to reduce carbon emissions such as carbon capture and storage rely on water availability for long-term success. Providing sufficient energy for all while radically reducing greenhouse gas emissions will require a paramount shift towards fossil-free energy use, very high energy efficiency, and equity. These goals may limit the availability of water resources for communities and ecosystems and result in a reduction of adaptive capacity for future change. For example, biofuels need vast quantities of water to grow the biofuel crop and process it into bioenergy, while large hydropower plants need to store vast quantities of water, especially during dry seasons, which could in certain instances hamper irrigated agriculture as an adaptation measure to combat climate-driven drought. In this case adaptation and mitigation measures are competing for water.

Another urgent mitigation challenge intimately linked to water is terrestrial carbon sequestration. Water in vegetation, soils and wetlands is the lock that seals carbon reservoirs, for example in peatlands, and provides necessary water for sustaining or restoring carbon storage by forests.

Climate change mitigation requires effective adaptation to succeed. The water cycle is sensitive to climate change and water is vital to energy generation and carbon storage. Water can also serve as a bridge to support both adaptation and mitigation. For instance, reforestation can reduce or prevent destructive surface runoff and debris flows from intensifying precipitation events by stabilizing hill slopes and promoting recharge. Strategic decisions should ideally acknowledge the turnover periods of technical systems, such as approximately 40 years for energy systems, in order to recognize the risks for technical lock-in in systems that lack robustness in coping with changes in climatic conditions and demand (IEA, 2012*a*).

Source: Karin Lexén, SIWI.

1.4 Interconnections

Interconnections between water, energy and other sectors means that policies that benefit one domain can translate to increased risks and detrimental effects in another; yet they can help generate co-benefits as well. The *2011/2012 European Report on Development* summarized it this way:

> A drop of water, a piece of land, or a kilojoule of renewable energy cannot be seen through the single lens of one sectoral policy or management system. What might appear to be an efficient policy in one dimension can be harmful for the others, and different ways of exploiting water and land or producing renewable energy place different stresses on the other resources. An adequate response to emerging challenges, and specifically the linkages between water, energy and land, make it imperative to examine and manage the trade-offs not only among users and uses of the same resource, but also of other related resources (EU, 2012, p. 5).

The well-documented case of how government-subsidized energy drove the expansion of irrigation in parts of India provides one example of such interconnections. In the western Indus-Ganges basin, a single line provided electrical power to both the irrigation and the domestic sectors, which meant the electricity utility was unable to charge a separate electricity tariff to groundwater irrigators (Box 16.1). Several decades of cheap energy, combined with the construction of millions of private wells, new pump technologies and water-inefficient irrigation practices, led to phenomenal growth in the exploitation of groundwater (World Bank, 2010*b*). This perverse link between energy subsidy policy and groundwater overdraft has left the state with a bankrupt electricity utility (Shah et al., 2008). By shielding farmers from the full cost of pumping, government electricity subsidies have established a pattern of groundwater use that has proved to be resistant to change. As a result, 29% of the country's groundwater assessment blocks are classified as semi-critical, critical or over-exploited, with the situation deteriorating rapidly (Garduno et al., 2011; Mukherji et al., 2009).

Similar experiences have been documented in Latin America and elsewhere (e.g. Oman and Yemen). With energy subsidies in place that reduce the cost of pumping, once irrigation reaches a certain level of profitability or there are limitations in surface water availability, regulatory measures become virtually ineffective in controlling groundwater extraction. The results are declining groundwater tables and, eventually, aquifer depletion. However, there are also counter-examples such as in Bangladesh, where subsidizing energy has benefited smallholder farmers without over-exploiting water resources (Section 6.6).

Climate change and variability further complicate the situation (Box 1.2). Major droughts and high temperatures can hinder the ability of the power sector to achieve sufficient cooling, leading to power outages. When the monsoon rains arrived late in 2012, leaving much of northern India in drought and extreme heat, farmers turned to electrical pumps to bring groundwater to the surface for irrigation. Electricity demand peaked at the same time that hydropower reservoirs were at their lowest, resulting in numerous blackouts. The reverse scenario can also occur: a problem with a power grid far away might become a local power outage that inhibits water production and treatment.

Other examples of water and energy interconnections include policies supporting the development of biofuels that have had negative impacts on land, water and food prices (Section 9.2.2). Replacing fossil fuels with biofuels in transport will measurably reduce the carbon footprint, but will also enlarge the water footprint of transport (UNEP, 2011*a*). Desalination of salt water and pumping of freshwater supplies over large distances may help reduce freshwater scarcity in certain places, but will also increase energy use. Conflicts over water between irrigation and hydropower (Section 6.2) provide yet another example.

Interconnections, however, need not necessarily have negative repercussions. In France, for example, under the RT 2020 sustainable energy framework all buildings by 2020 will produce more energy than they consume, and they will also purify and recycle water naturally. Such policies are driving the development of innovative technologies; for example, a system that filters wastewater for use as grey water while at the same time harnessing the energy-generating potential of the algae present in the wastewater. An added benefit of this approach is that it reduces the volume of wastewater returning to the treatment plant, ultimately resulting in energy savings.

Women and children represent a disproportionately large fraction of the bottom billion, the poorest one billion people on Earth, and, as such, have the most to gain from poverty reduction measures centred on improving access to water supply and energy services (Box 1.3). In most cases, service provision to the poor would not significantly affect access to other users.

BOX 1.3

Gender and equity dimensions

The term 'bottom billion' refers to the world's population living on less than US$1.25 per day. Most of these people suffer from malnutrition and lack access to safe water supplies and electricity (or other forms of upgraded energy). Providing these basic services is a key factor in lifting these and other poor people out of poverty and helps create opportunities for generating income. In Lima, Peru, the experience of the Water for All Programme suggests that providing urban families in extreme poverty with a connection to piped water services, without any additional (permanent) subsidy, resulted in a total increase in disposable family income of 14% per month (CEPAL, 2011).

In developing countries, women and girls bear most of the work burden associated with managing water and energy scarcity, fetching water for the 780 million people lacking access to improved sources of drinking water (WHO/UNICEF, 2012) and collecting firewood for the 2.7 billion depending on traditional biomass for cooking (UNEP, 2011*b*). This adds to their time and work burdens and seriously compromises their educational and employment opportunities, perpetuating the intergenerational transfer of poverty and disempowerment. Available statistics often fail to recognize or measure their real contributions to their economies and communities as unpaid water and energy providers.

Water and firewood collection can place women and girls at increased risk of sexual or physical assault, especially at night in the absence of adequate street lighting. The over-reliance on wood, straw, charcoal or dung for cooking and heating is detrimental to women and children's health – they account for more than 85% of the two million deaths each year attributed to cancer, respiratory infection and lung disease due to indoor air pollution (UNDP/WHO, 2009). It is estimated that by 2030 more than 4,000 people will die prematurely each day from household air pollution (IEA, 2010). Women and girls are also the most exposed to waterborne diseases (WWAP, 2012).

Source: UN Women.

CHAPTER
2

Water: Demands, energy requirements and availability

WWAP | Richard Connor and Michael Webber

2.1 External pressures that drive the demand for water

Alongside natural forces affecting the world's water systems, human activities interact and unite to create pressures on water resources, for which there are no substitutes. These pressures are in turn affected by a range of factors such as technological development, political, institutional and financial conditions, and climate change.

Global population is projected to reach 9.3 billion in 2050 (UNDESA, 2012). Population growth leads to increased water demand, reflecting growing needs for drinking water, health and sanitation, as well as for energy, food and other goods and services that require water for their production and delivery. Urban areas of the world, particularly those in developing countries, are expected to absorb all this population growth, at the same time drawing in some of the rural population. This intense urbanization will increase demand for water supply, sanitation services and electricity for domestic purposes (Chapter 7).

In the absence of sustainable resource management practices for limiting the impact of wasteful consumption and unsustainable resource use, economic development can negatively impact water supplies in terms of quality and quantity. Consumer demand and increasing standards of living are driving increased demand for water, most notably by middle income households in developing and emerging economies through their greater demand for food, energy and other goods, the production of which can require significant quantities of water.

Water of acceptable quality and in adequate quantity is needed to meet food production demands. At the same time, food production and supply have a negative impact on the sustainability and quality of water resources. Agriculture is the biggest water user, with irrigation accounting for 70% of global water withdrawals (Chapter 6). With increasing demand for food, competition for water is rising. Specialized crops and livestock products often require more water (and in most cases more energy) to produce and lead to higher levels of water pollution. In the pursuit of food security, technological advancements in the agricultural sector could have significant impacts, both positive and negative, on water demand, supply and quality.

Paradoxically, technical progress aimed at improving resource use efficiency may not always serve the intended goal of decreasing resource consumption. In terms of water (as for energy), the implementation of resource-saving technologies may indeed decrease per unit consumption, but the savings are often immediately 'reinvested' to increase production and thus do not lead to an overall decrease in demand. This has often been the case for agriculture and industry (Chapter 8). Technology can also create rapid, dramatic and unexpected changes (both in terms of pressures and solutions), making it the most unpredictable driver (WWAP, 2009). This is particularly true in the context of water and energy, where technologies to improve the efficiency or productivity in one domain can have an opposing effect on the other. For example, the rapid dispersion of energy technologies, such as the combination of horizontal drilling and hydraulic fracturing in areas with scarce or variable water supplies, can lead to significant localized water stress (Section 3.2.1).

Climate change impacts the hydrological cycle and consequently impacts water resources. It is an additional stressor through its effects on other external pressures and thus acts as an amplifier of the already intense competition for water resources. For example, higher temperatures and an increase in the rate of evaporation may affect water supplies directly and potentially increase the water demand for agriculture and energy. Significant levels of uncertainty exist with respect to climate change projections, and these uncertainties increase greatly when focusing on local scales. Water resources management is in a difficult transition phase, trying to accommodate large uncertainties associated with climate change while struggling to implement a difficult set of principles and institutional changes associated with integrated water resources management (Stakhiv, 2011).

Government policies concerning water and water-related sectors, including agriculture and energy, as well as environmental protection, can obviously exacerbate or alleviate pressures on water resources. The challenge facing government lies in better coordinated planning and assessing trade-offs at the national level (Chapter 5). Investment by both the public and the private sectors will be a determining factor for the levels to which the provision of water and water-related services will increase.

Consumer demand and increasing standards of living *are driving increased demand for water, most notably by middle income households in developing and emerging economies through their greater demand for food, energy and other goods, the production of which can require significant quantities of water*

2.2 Current global water demand and projected increases

Data on water use (withdrawals and consumption)[6] and quality are very often outdated, limited or unavailable. When available, they are often based on estimates rather than actual measurements. Globally, total freshwater withdrawals are believed to have increased by about 1% per year between 1987 and 2000, based on data obtained from FAO AQUASTAT. It is reasonable to assume this trend overall has continued since then at a similar rate to the present. Annual freshwater withdrawals appear to have stabilized or even declined in the majority of the world's most highly developed countries, suggesting improvements in efficiency and increasing reliance on the importation of water intensive goods, including food (Gleick and Palaniappan, 2010). This also suggests that the 1% annual global increase has been occurring almost exclusively in developing countries.

Agriculture accounts for roughly 70% of total freshwater withdrawals globally, with the industrial and domestic sectors accounting for the remaining 20% and 10%, respectively, although these figures vary considerably across countries. More-developed countries have a much larger proportion of freshwater withdrawals for industry than less-developed countries, where agriculture dominates. Agriculture accounts for more than 90% of freshwater withdrawals in most of the world's least-developed countries (LDCs) (FAO, 2011*a*). Historically, 'energy' (fuel and power generation) has not normally been considered as a stand-alone sector when reporting on water use. Water use for energy has most often been embedded in 'industry'. However, the IEA has estimated global water withdrawals for energy production in 2010 accounted for roughly 15% of the world total (IEA 2012*a*), or roughly 75% of all industrial water withdrawals.

While there is wide recognition for the need to allocate water to ecosystems (WWAP, 2009), and significant progress has been made on methodologies to quantify ecosystem requirements (Poff et al., 2010), there is less systematic information on where and to what extent the maintenance of environmental flows has actually been applied.

The global demand for water is expected to grow significantly for all major water use sectors, with the largest proportion of this growth occurring in countries with developing or emerging economies. However, quantifying potential increases in water demand is extremely difficult, as 'there are major uncertainties about the amount of water required to meet the [growing] demand for food, energy and other human uses, and to sustain ecosystems' (WWAP, 2012, p. 2). Without improved efficiencies, agricultural water consumption is expected to increase by about 20% globally by 2050 (WWAP, 2012). Domestic and industrial water demands are also expected to increase, especially in cities and countries undergoing accelerated economic growth and social development. Water demand for energy will certainly increase as energy demand is expected to increase by more than one-third in the period 2010–2035, with countries outside the Organisation for Economic

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[6] *Withdrawal* is the total amount of water taken from a lake, river or aquifer for any purpose. *Consumption* is the fraction of withdrawn water that is lost in transmission, evaporation, absorption or chemical transformation, or otherwise made unavailable for other purposes as a result of human use.

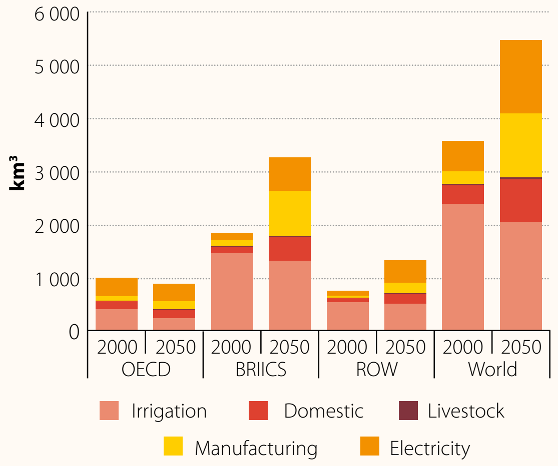
> *The global demand for water is expected to grow significantly for all major water use sectors, with the largest proportion of this growth occurring in countries with developing or emerging economies.*

Co-operation and Development (OECD) accounting for 90% of demand (IEA, 2012*a*) (Chapter 3).

According to the OECD, in the absence of new policies (i.e. the Baseline Scenario), freshwater availability will be increasingly strained through 2050, with 2.3 billion more people than today (in total more than 40% of the global population) projected to be living in areas subjected to severe water stress, especially in North and South Africa and South and Central Asia. Global water demand in terms of water withdrawals is projected to increase by some 55% due to growing demands from manufacturing (400%), thermal electricity generation (140%) and domestic use (130%) (OECD, 2012*a*) (Figure 2.1). It should be noted that these calculations do not take environmental flows into account, necessary for the future delivery of water supply and water-based ecosystem services.

FIGURE 2.1

Global water demand (freshwater withdrawals): Baseline Scenario, 2000 and 2050



Note: BRIICS, Brazil, Russia, India, Indonesia, China, South Africa; OECD, Organisation for Economic Co-operation and Development; ROW, rest of the world. This graph only measures 'blue water' demand and does not consider rainfed agriculture.
Source: OECD (2012a, fig. 5.4, p. 217, output from IMAGE). OECD Environmental Outlook to 2050 © OECD.

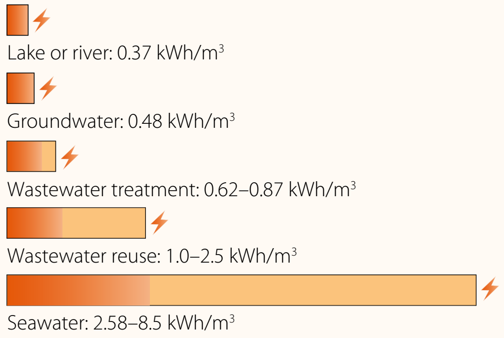
2.3 Energy requirements for water provision

Energy is required for two components of water provision: pumping and treatment. The energy needed for pumping water depends on elevation change (including depth in the case of groundwater), distance, pipe diameter and friction. Pumping water requires a lot of energy because of its high density. The amount of energy needed in water and wastewater treatment processes varies greatly and is dependent upon factors such as the quality of the source water, the nature of any contamination, and the types of treatment used by the facility (Section 7.3).

Different levels of treatment are required for different uses. Drinking water typically requires extensive treatment, and once used, it needs to be treated again to reach a standard safe for return to the environment. Many of these steps are highly energy intensive. Some treatment processes, such as ultraviolet (UV), consume relatively little energy (0.01–0.04 kWh/m^3). More sophisticated techniques, such as reverse osmosis, require larger amounts (1.5–3.5 kWh/m^3). Water for agriculture generally requires little or no treatment, so energy requirements are mainly for pumping (Section 6.4). Globally, the amount of energy used for irrigation is directly related to the enormous quantities of water required for irrigation and the irrigation methods used.

FIGURE 2.2

Amount of energy required to provide 1 m³ water safe for human consumption from various water sources



Note: This diagram does not incorporate critical elements such as the distance the water is transported or the level of efficiency, which vary greatly from site to site.
Source: WBSCD (2009, fig. 5, p. 14, based on source cited therein).

Surface water, when located near delivery points, is usually the least energy intensive to distribute, but can be highly polluted. Groundwater generally requires little treatment, but more energy to pump it to the surface. Brackish groundwater requires significant energy for treatment, depending on the level of total dissolved solids in the water (the more salts to be removed, the more energy required). Seawater desalination is at the high end of the energy intensity scale, with energy requirements being a function of water temperature and salinity (Figure 2.2).

Growth in desalination has increased significantly over the past 20 years as countries seek to augment natural water supplies and as the combined energy and industrial costs have reportedly dropped to below US\$0.50/m^3 (IRENA, 2012*a*). There are currently more than 16,000 desalination plants worldwide, with a total global operating capacity of roughly 70 million m^3/day (IDA, n.d.). Some industry observers have suggested operating capacity could nearly double by 2020. Desalinated water involves the use of at least 75.2 TWh/year, which is about 0.4% of global electricity consumption (IRENA, 2012*a*). Although this technology may be appropriate for supplementing water supplies for some domestic and industrial users in middle and high income regions near the coast, it is currently not an affordable alternative for the poorest countries, for large water consuming sectors such as agriculture, or for consumption at a distance from the plant due to transportation costs. There are promising advances in desalination (Section 5.2.1; Box 12.2) though at the same time it is recognized that increased salinity levels in seawater caused by desalination can have negative impacts on local marine ecosystems.

Groundwater is the primary source of drinking water worldwide, and in countries such as Denmark and Mexico comprises a significant portion of water supply (99% and 95%, respectively) while the same ratio is 38% for the United States of America (USA) (Chilton, 2002; Kenny et al., 2009). Groundwater pumping typically requires around 0.1 kWh/m^3 at 36.5 m depth to 0.5 kWh/m^3 at 122 m depth (US GAO, 2011). Groundwater is often cited as a high quality source that requires less treatment than surface water. When groundwater is relatively free of microbial contamination and any chemical contamination is localized, its treatments costs can be much lower than surface water. For example, in Canada, operation and maintenance costs (including energy and labour) of plants treating groundwater are approximately half on average of those treating surface water (Statistics Canada, 2011). More than 17% of Canadian groundwater requires no treatment and nearly 30% requires only disinfection. Given that the depth of wells, and therefore pumping costs, are dependent on groundwater level, ensuring adequate recharge rates can result in long-term cost and energy savings. In this regard, sustainable groundwater management, including managing aquifer recharge (Box 2.1), can lead to positive benefits.

> ***An interesting and notable flip side of the water–energy nexus*** *is that wastewater is becoming recognized as a potential source of energy rather than as a mere waste stream. In several countries, water supply companies are working towards becoming energy neutral.*

2.1

BOX

Aquifer recharge

Managed aquifer recharge (MAR) is the process of intentionally banking, and in some cases treating, water in aquifers. MAR is used both to prevent degradation of groundwater resources and to generate additional sources of drinking water via storage or bioremediation of wastewater. There are several types of MAR, some of which require energy (e.g. aquifer storage and recovery) and some of which do not (e.g. infiltration ponds) (Dillon, 2005; Tuinhof et al., 2012). Energy consumptive MAR are used mostly in the USA and in Australia, while non-consumptive MAR are used in nearly every region of the world (Tuinhof et al., 2012).

The use of MAR to create or augment existing water supplies could have measurable energy savings and carbon emission reductions. For example, a study examining parts of the San Francisco Bay Area showed that creating local water supplies could save 637 million kWh/year. Given that the energy required to pump groundwater increases with depth, preventing groundwater depletion also results in long-term energy savings (US DOE, 2006).

Source: Kirstin I. Conti, IGRAC and University of Amsterdam.

An interesting and notable flip side of the water–energy nexus is that wastewater is becoming recognized as a potential source of energy (Sections 5.2.4, 7.4.3; Box 16.4) rather than as a mere waste stream. In several countries, water supply companies are working towards becoming energy neutral; they intend to generate an amount of energy from wastewater that equals the amount of energy consumed in their other operations.

See Chapters 17 and 24 (Volume 2) for the case studies 'Green energy generation in Vienna, Austria' and 'Green energy production from municipal sewage sludge in Japan', respectively.

2.4 Water availability

While data on precipitation – which can be measured with relative ease – are generally available for most countries, river runoff and groundwater levels are generally much more difficult and costly to monitor. As a result, trends regarding changes in the overall availability of freshwater supplies are difficult to determine in all but a few places in the world. However, it is clear that several countries face varying degrees of water scarcity, stress or vulnerability (Figure 2.3).[7]

In the absence of flow regulation by artificial storage infrastructure, the availability of surface water varies from place to place across days, seasons, years and decades as a function of climate variability. Climate change means past hydrological trends are no longer indicative of future water availability. According to the most recent climate projections from the Intergovernmental Panel on Climate Change (IPCC) (2008), dry regions are to a large extent expected to get drier and wet regions are expected to get wetter, and overall variability will increase. There is mounting evidence that this is indeed happening as a result of an intensification of the water cycle (Durack et al., 2012) and it is affecting local regional water supplies, including those available for energy production.

There is clear evidence that groundwater supplies are diminishing, with an estimated 20% of the world's aquifers being over-exploited, some massively so (Gleeson et al., 2012). Globally, the rate of groundwater abstraction is increasing by 1% to 2% per year (WWAP, 2012),

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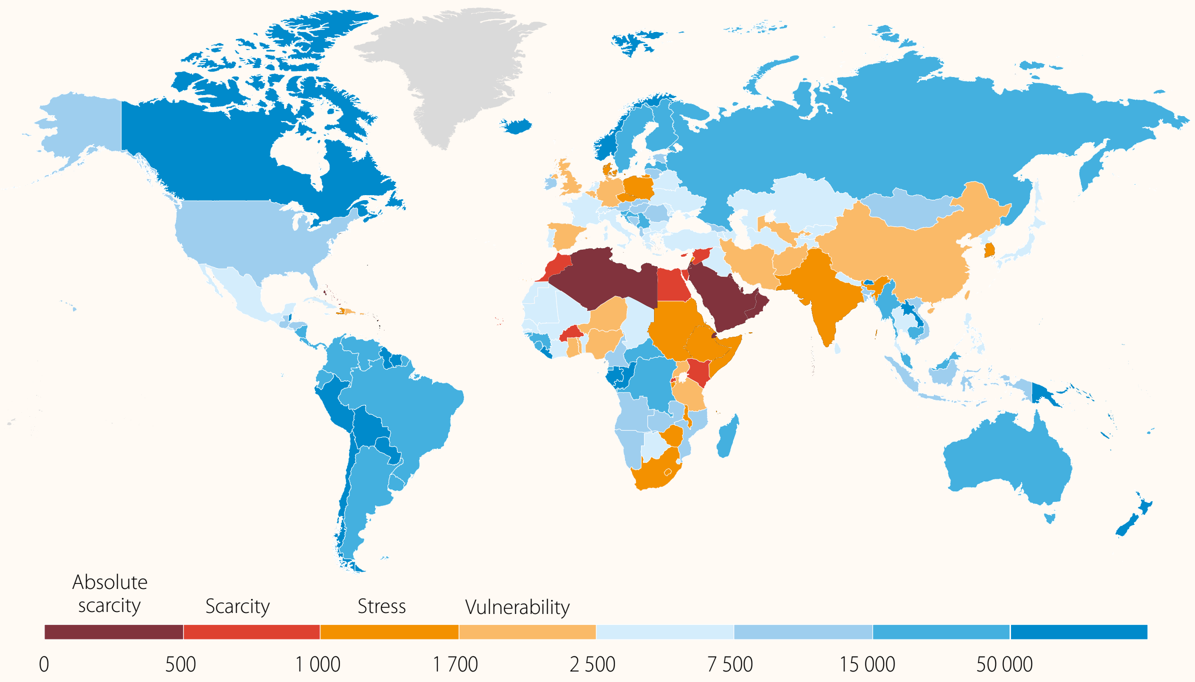
[7] For more detailed information on water availability, stress and scarcity, see WWAP (2012, section 4.6, 'In or out of balance?').

FIGURE 2.3

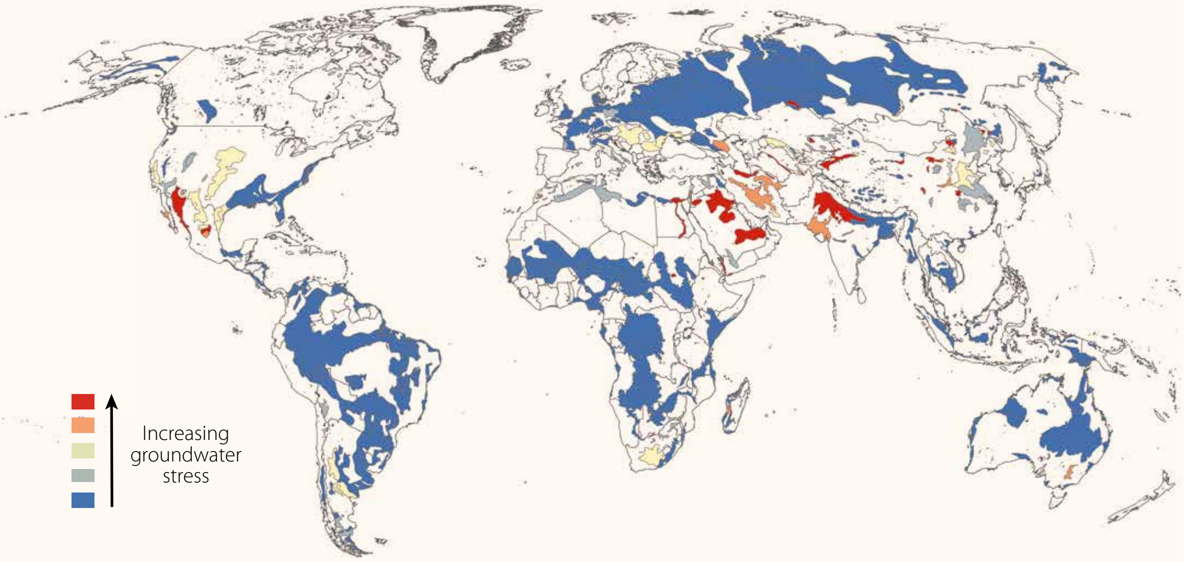
Total renewable water resources, 2011 (m³ per capita per year)



Source: WWAP, prepared with data from FAO AQUASTAT (aggregate data for all countries except Andorra and Serbia, external data) (website accessed Oct 2013), and using UN-Water category thresholds.

FIGURE 2.4

Water stress of aquifers important for farming



Source: Gleeson et al. (2012, fig. 1, as appears in Nature News, http://www.nature.com/news/demand-for-water-outstrips-supply-1.11143#/ref-link-1).

adding to water stress in several areas (Figure 2.4) and compromising the availability of groundwater to serve as a buffer against local supply shortages.

Water quality is also a key determinant of water availability, although potable water is not required for all purposes. Polluted (or saline) water cannot be used for several crucial purposes such as drinking and hygiene. However, for other purposes such as agriculture and certain industries, use of slightly polluted water or partially treated wastewater can be considered. This provides an opportunity to use reclaimed wastewater and stormwater, reducing the cost and energy consumption associated with water treatment (Section 7.4.2).

Although there have been some local successes in improving water quality (mainly in developed countries), there are no data to suggest an overall improvement in water quality at the global scale. Deterioration of wetlands worldwide further contributes to reduced potential in ecosystems' capacity to purify water. It is estimated that more than 80% of used water worldwide – and up to 90% in developing countries – is neither collected nor treated (WWAP, 2012), threatening human and environmental health.

> ***There is clear evidence** that groundwater supplies are diminishing, with an estimated 20% of the world's aquifers being over-exploited, some massively so. Globally, the rate of groundwater abstraction is increasing by 1% to 2% per year.*

CHAPTER 3

Energy’s thirst for water

WWAP | Richard Connor, Ingvar B. Fridleifsson, Michael Webber and James WInpenny

3.1 Global energy demand

Many of the external pressures that drive the increasing demands for water (Section 2.1) also play influential roles in the growing demand for energy. Both are fundamentally driven by (and drivers of) social development and economic growth, and both are strongly influenced by economic forces, increasing living standards, technological development and government policy. One of the main differences, as detailed in Chapter 1, is that market forces have tended to play a much more important role with respect to energy sector development, whereas the management of water resources and the improvement of water-related services have historically been more of a socio-political prerogative.

Progressive energy access programmes, accelerated urbanization and rapid economic development in some developing countries have provided access to modern energy services for hundreds of millions of people over the past two decades, especially in China and India. However, nearly one-fifth of the global population, close to 1.3 billion people, did not have access to electricity in 2010, and roughly 2.6 billion people relied on the traditional use of biomass for cooking (IEA, 2012*a*) (Table 1.1).

Global energy demand is expected to grow by more than one-third over the period to 2035, with China, India and the Middle East accounting for about 60% of the increase, according to the IEA’s New Policies Scenario (IEA, 2012*a*) (see Box 3.1 for a description of IEA scenarios).

The IEA’s *World Energy Outlook 2012* estimates global water withdrawals for energy production in 2010 at 583 billion m^3 (representing some 15% of the world’s total withdrawals), of which 66 billion m^3 was consumed (IEA, 2012*a*). By 2035, according to its New Policies Scenario (Box 3.1), withdrawals would increase by 20%, whereas consumption would increase by 85%, driven by a shift towards higher efficiency power plants with more advanced cooling systems (that reduce withdrawals but increase consumption) and due to increased production of biofuel.

3.1.1 Water’s role in meeting the growing energy demand

Water is crucial for energy. Water is used in the extractive industries for producing fuels such as coal, uranium, oil and gas. Water is an input for energy crops such as corn and sugar cane for ethanol and biomass for fuel pellets. Water is also crucial for cooling purposes in most power plants and the driving force for hydroelectric and steam turbines.

BOX 3.1

Scenarios of the International Energy Agency’s *World Energy Outlook 2012*

The *Current Policies Scenario* exclusively considers the effects of those government policies and measures that had been enacted or adopted by mid-2012. This scenario does not take into account any possible, potential or even likely future policy actions.

The *New Policies Scenario* is the central scenario of the IEA’s world energy model. This scenario takes into account broad policy commitments and plans that have been announced, even where the specific measures to implement these commitments have yet to be introduced, in addition to those that have already been implemented to address energy-related challenges.

The *450 Scenario* deliberately selects a plausible energy pathway consistent with actions having about a 50% chance of meeting the goal of limiting the global increase in average temperature to 2°C in the long term, compared with pre-industrial levels. To meet this goal, the long-term concentration of greenhouse gas in the atmosphere needs to be limited to around 450 p.p.m. CO_2-eq – hence the scenario’s name.

Source: WWAP, from IEA (2012a).

In some places, water is used for transporting fuels, such as waterways throughout Europe and many parts of Asia that float barges carrying coal from mines to power plants. In other places water is used to permit coal slurry to be transported from coal mines to power plants through pipelines.

Energy accounts for a significant fraction of a country's water use (both consumptive and non-consumptive). In developing countries, 10% to 20% of withdrawals are used to meet industrial needs, including energy (Boberg, 2005). In some developed countries, where a smaller fraction is used for agriculture, more than 50% of water withdrawals are used for power plant cooling alone (Section 3.3.1).

The following sections describe the potential implications and impacts of energy production on water and examine supply and demand trends for different forms of primary energy[8] and electrical power generation.

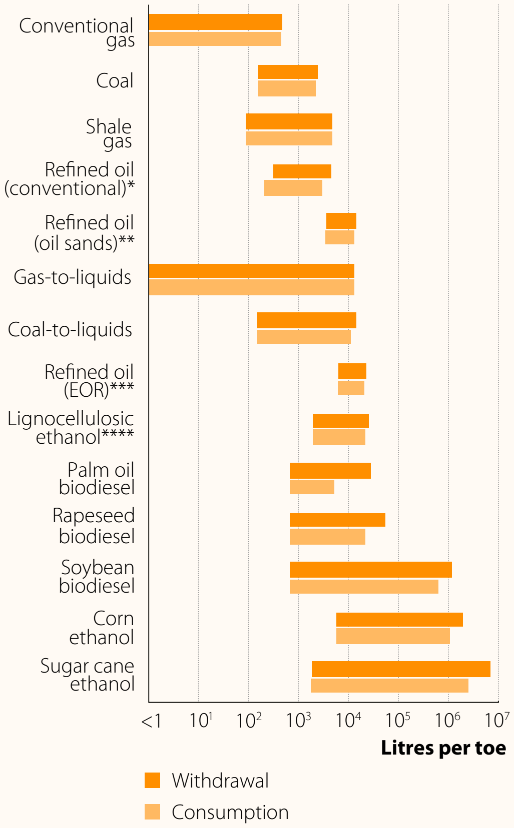
3.2 Primary energy

Water is used to produce fuels in the extractive industries in a variety of ways, each requiring different quantities of water (Figure 3.1). For example, many coal seams need to be dewatered before mining can commence. That water use is often classed as consumptive because the water might not subsequently be available for other uses. Water is also used for leaching minerals in uranium mining, with significant impacts on the downstream environment. Significant volumes of water are used for oil and gas production. Generally, biofuels require more water per unit energy than extracted fuels because of the water needed for photosynthesis, and unconventional fossil fuels require more water than conventional fossil fuels.

There is evidence that demand for all types of primary energy will increase over the period 2010–2035 (IEA, 2012*a*) (Figure 3.2). Despite the ongoing progress of 'clean' technology policies promoting renewables, the world's global energy system appears to remain on a relatively fixed path with respect to its continued reliance on fossil fuels. A shift away from oil and coal (and, in some countries, nuclear power) is expected in OECD countries, where energy demand is not expected to rise appreciably. Despite the growth in low carbon sources of energy, however, fossil fuels are expected to remain dominant in the global energy mix (IEA, 2012*a*).

FIGURE 3.1

Water withdrawals and consumption vary for fuel production



** The minimum is for primary recovery; the maximum is for secondary recovery. ** The minimum is for in-situ production, the maximum is for surface mining. *** Includes carbon dioxide injection, steam injection and alkaline injection and in-situ combustion. **** Excludes water use for crop residues allocated to food production.*

Note: toe, tonne of oil equivalent (1 toe = 11.63 MWh = 41.9 GJ). Ranges shown are for 'source-to-carrier' primary energy production, which includes withdrawals and consumption for extraction, processing and transport. Water use for biofuels production varies considerably because of differences in irrigation needs among regions and crops; the minimum for each crop represents non-irrigated crops whose only water requirements are for processing into fuels. EOR, enhanced oil recovery. For numeric ranges, see http://www.worldenergyoutlook.org.

Source: IEA (2012a, fig. 17.3, p. 507, based on sources cited therein). World Energy Outlook 2012 © OECD/IEA.

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[8] The term 'primary energy' is associated with any energy source that is extracted from a stock of natural resources or captured from a flow of resources and that has not undergone any transformation or conversion other than separation and cleaning. Examples include coal, crude oil, natural gas, solar power and nuclear power.
'Secondary energy' refers to any energy that is obtained from a primary energy source by a transformation or conversion process. Thus oil products or electricity are secondary energies as these require refining or electric generators to produce them (IEA, 2004).

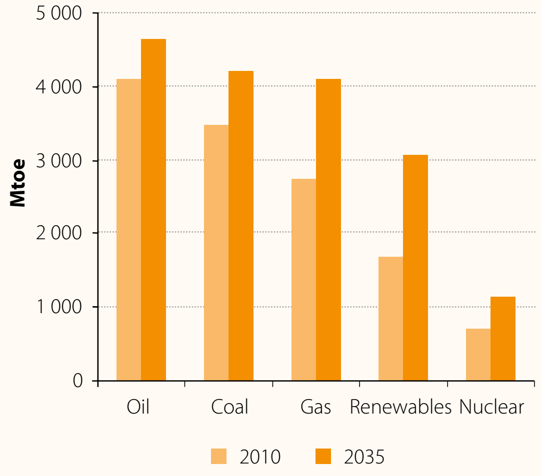
There is evidence that demand for all types of primary energy will increase over the period 2010–2035

3.2.1 Fossil fuels

Coal mining uses large volumes of water for various processes (Figure 3.1), and discharges to natural water bodies may be contaminated, while underground operations may disrupt and contaminate aquifers.

For conventional oil and gas production, water injection (sometimes referred to as waterflooding) is used to pressurize fields, increasing productivity. Oil and gas extraction yields high volumes of 'produced water', which is water that comes out of the well along with the oil and gas. Produced water usually has very high salinity and is difficult to treat (Section 9.2.3). Underground injection into saline aquifers is one disposal method, although the water can also be treated and reused. In many cases, the volume of produced water far exceeds the volume of fuel produced.

FIGURE 3.2 **World primary energy demand by fuel in the New Policies Scenario**



Note: 'Renewables' includes bioenergy, geothermal, hydropower, solar photovoltaic (PV), concentrating solar power (CSP), wind and marine (tide and wave) energy for electricity and heat generation. See Box 3.1 for an explanation of the New Policies Scenario.
Source: IEA (2012a, fig. 2.3, p. 54). World Energy Outlook 2012 © OECD/IEA.

Water is used as a process input and a feedstock for process steam at refineries to upgrade crude into higher value products. Typical volumes of water needed end-to-end (from extraction through refining) for petroleum-based fuels are 7–15 litres water per litre fuel (Beal, 2012; Sanders and Webber, 2012). For natural gas, the volumes of water are approximately 20–50 litres water per barrel equivalent of oil (Lutz et al., 2013).[9]

Unconventional oil and gas production is generally more water intensive than conventional oil and gas production. For oil sands production in Canada and heavy oil production in Venezuela, water is used to make steam to reduce the viscosity of the fuel, easing production. Water is also a critical input for hydraulic fracturing, or 'fracking' (Box 3.2).

For hydraulic fracturing, typical water injection volumes are 8–30 million litres per well. Approximately 250 tonnes of proppant, such as sand, is injected to hold the cracks open to increase the gas flows. The typical composition of fracking fluids is 98% sand and water and 2% chemicals (acids, surfactants, biocides and scaling inhibitors), which are added to increase productivity. As producers become more water efficient, using less water per well, the relative proportion of chemicals increases. A significant fraction of the injected fluid comes back out of the wells as wastewater (including drilling muds, flowback water and produced water). The volume of produced water that is returned varies greatly, depending on the geological characteristics of the formation; it can be as low as 15% and as high as 300%[10] of the injected volume.

The water intensive process produces large volumes of wastewater with high salinity and potential for containing naturally occurring radioactive materials. Further risks to water quality can occur from storage pits that are not properly lined (allowing the wastewater to trickle down into the groundwater), from spills by trucks that carry the wastewater, or by injection into waterways from wastewater treatment plants that do not adequately treat the produced water.

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[9] For more on the water intensity of transportation fuels, see WWAP (2012, fig. 19.5).

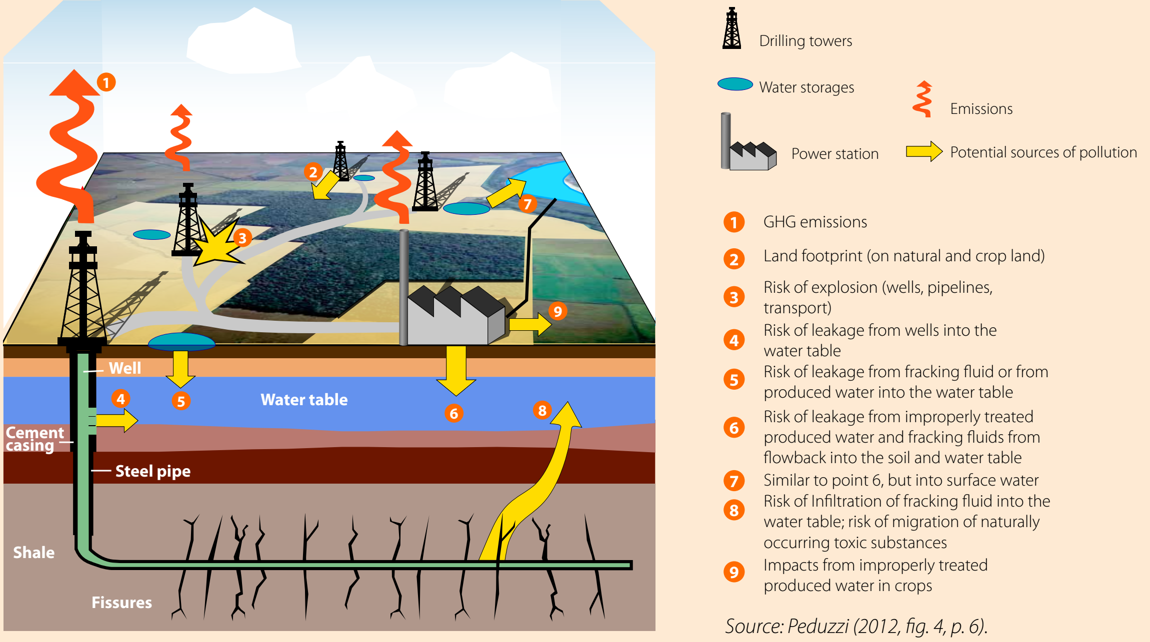
[10] Some wells yield higher volumes of produced water than the amount of original water that was injected.

3.2 BOX

Hydraulic fracturing: Prospects and limitations of the natural gas future

Increasing energy demands and decreasing availability of conventional fuels has quickly transformed natural gas extraction from shale formations into a potentially significant energy solution for the coming decades. The controversy generated by its potential environmental impacts has arisen equally fast, especially due to risks affecting groundwater resources used for drinking water supply.

Schematic representation of infrastructures and potential impacts



① GHG emissions
② Land footprint (on natural and crop land)
③ Risk of explosion (wells, pipelines, transport)
④ Risk of leakage from wells into the water table
⑤ Risk of leakage from fracking fluid or from produced water into the water table
⑥ Risk of leakage from improperly treated produced water and fracking fluids from flowback into the soil and water table
⑦ Similar to point 6, but into surface water
⑧ Risk of Infiltration of fracking fluid into the water table; risk of migration of naturally occurring toxic substances
⑨ Impacts from improperly treated produced water in crops

Source: Peduzzi (2012, fig. 4, p. 6).

The total amount of the world's technically recoverable gas resources would increase more than 40% if all the shale gas resources were added to the already identified conventional gas resources (US EIA, 2011). This newly available energy source could cover 30% of the world's total primary energy supply by 2050 (EC, 2012*a*).

The use of 'fracking' in conjunction with horizontal drilling has opened up natural gas resources that had previously not been commercially viable (US EIA, 2010*b*). Increasing development of these unconventional resources is closely linked to the improvement of fracking technologies. Fracking is a part of the production process, even though it is commonly confused with the complete process, which includes well construction, hydraulic fracturing, production and closure (Cooley and Donnelly, 2012).

Social awareness about the potential risks of fracking techniques has fostered research on the environmental impacts: land-take, air pollution, noise pollution, water contamination and withdrawal, biodiversity impacts and seismicity (EC, 2012*b*). Public concern is especially focused on the risks affecting drinking water resources. In fact, evidence of a relationship between methane contamination of shallow aquifers and shale gas exploitation has been recently documented (Osborn et al., 2011). Drinking water resources as well as ecosystems can be affected by contaminated water (Haluszczak et al., 2013) released by the well after injection.

Besides groundwater pollution risks, local groundwater consumption by fracking might become a limiting factor, especially in arid regions where groundwater resources are generally available, unlike surface water. The fracturing process of a single well requires 7,000–18,000 m^3 water (Arthur et al., 2008) distributed along a period of 30–40 years (Nicot and Scanlon, 2012). The aquifer replenishment capacity of this temporally intense groundwater demand needs to be tackled during project design, while considering possible conflicts with other groundwater uses.

Other potential impacts from fracking processes are related to chemical mixing or wastewater treatment and disposal (US EPA, 2012; Howarth et al., 2011).

Source: Laura del Val Alonso, IGRAC.

Coal met 45% of the growth in global energy demand over the past decade (IEA, 2012*a*). Policy decisions, including possible measures to cut coal-related greenhouse gas (GHG) emissions and to develop and deploy CCS will determine whether demand carries on rising strongly or changes course radically. In the power sector, inter-fuel competition with renewables and gas can also affect coal demand (IEA, 2012*a*).

Growth in oil consumption in emerging economies (China, India and the Middle East) is likely to outweigh reduced demands in OECD countries, pushing global oil demand steadily higher over the next two decades (IEA, 2012*a*).

Demand for natural gas is expected to increase as a result of rapid growth in developing countries, led by China (IEA, 2012*a*). Abundant supplies in North America are likely to spur growth in natural gas development in the USA and Canada, and lower natural gas prices may lead to a significant shift towards the increasing use of gas in power generation and transport.

The development of unconventional gas resources (i.e. shale gas) appears to be on a fast track in Australia, China and the USA. There are several other countries where shale gas resource estimates are high (above 5.6 km^3) and there exists a significant natural gas production infrastructure for internal use or for export, including Algeria, Argentina, Brazil, Canada, Libya and Mexico (US EIA, 2011). However, regulatory uncertainties linked to environmental and health concerns are likely to slow down shale gas development in many of these countries (IEA, 2012*a*). Water limitations have also stymied development of shale gas resources in certain areas. Significant shale gas development could also emerge in countries that have at least some gas production infrastructure and whose estimated shale gas resources are substantial relative to their current levels of consumption, which are currently met by natural gas imports. Examples of countries in this group are Chile, France, Morocco, Poland, South Africa, Turkey and Ukraine (US EIA, 2011).

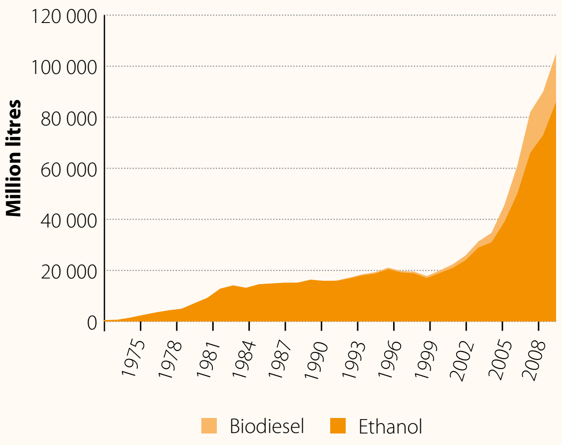
3.2.2 Biofuels

In 2010, traditional biomass represented 9.6% of global final energy consumption (Figure 9.2), whereas modern biofuels represent only 0.8% of global final energy consumption (Banerjee et al., 2013, fig. 4.1). But the contribution of biofuels to energy supply is expected to grow rapidly, with beneficial impacts including reduction in GHGs, improved energy security and potential new income sources for farmers (de Fraiture et al., 2008).

However, local and regional impacts of biofuels could be substantial, as they are among the most water intensive types of fuel production (Figure 3.1). Biomass production for energy will compete with food crops for scarce land and water resources, already a major constraint on agricultural production in many parts of the world. China and India, the world's two largest producers and consumers of many agricultural commodities, already face severe water limitations in agricultural production, yet both have initiated programmes to boost biofuel production (de Fraiture et al., 2008). The potential impacts of biofuels on water resources and the impacts of bioenergy on ecosystems are discussed in detail in Sections 6.5 and 9.2.2, respectively.

Biofuel production has increased dramatically since 2000 (Figure 3.3). Biofuel was originally perceived as a sustainable ('green') alternative to GHG-emitting oil and gas for transportation (primarily). Propelled in part by rising oil prices, the macroeconomic trading environment, and energy security concerns, biofuel policies in the European Union (EU) have been reconsidered due to growing recognition of their adverse effects on land, water and the environment. Understanding of short-term climate mitigation benefits of biofuels has also been revised; it has been estimated that biofuels will achieve net GHG savings only after 2030 (IIASA, 2009).

FIGURE 3.3 **World ethanol and biodiesel production, 1975–2010**



Source: Shrank and Farahmand (2011, fig. 1, from source cited therein).

Global production of ethanol and biodiesel is projected to expand, but at a slower rate than in the past. Ethanol production is dominated by the USA, Brazil and, to a lesser extent, the EU and China. Biofuel production in many developing countries is projected to remain below expressed targets, as the cultivation of non-edible biofuel crops (i.e. 'biomass based [second generation]' in Figure 3.4) remains, in most cases, on a project or small-scale level, and the high price of agricultural commodities does not encourage their use as biofuel feedstock. The high price of crude and policies promoting biofuel usage strongly affect biofuel markets (OECD/FAO, 2012). Subsidies continue to be a major driver of biofuel expansion (Webb and Coates, 2012).

3.3 Electrical power generation

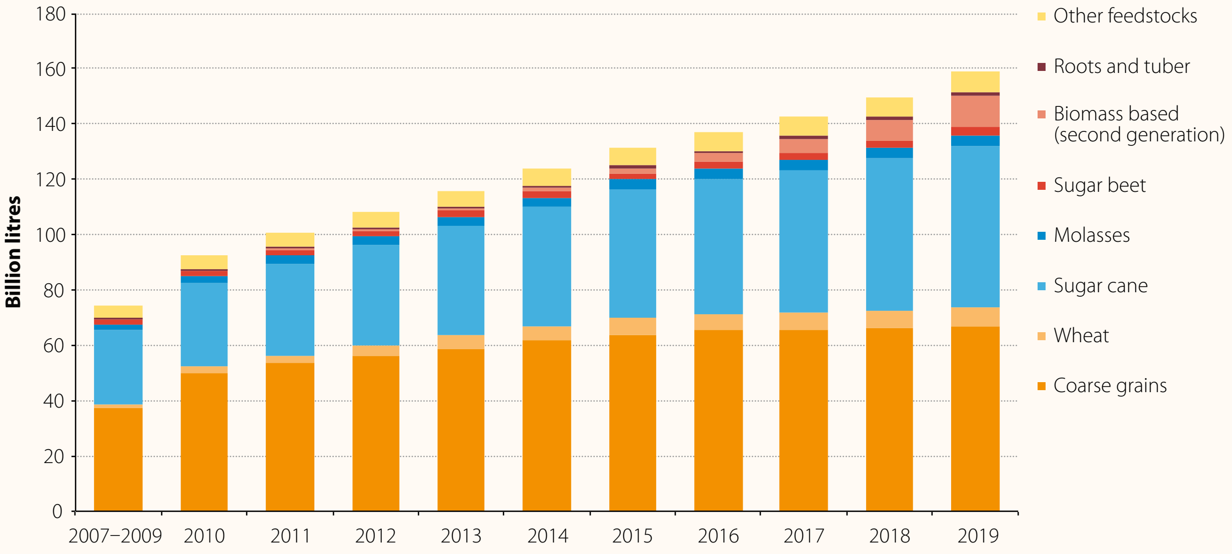
Approximately 90% of global power generation is water intensive. Water is used directly for hydropower generation as well as for all forms of thermal power generation schemes. Water also indirectly enables power generation through the cooling it provides for the vast majority of thermal power plants. These plants use heat (from nuclear, coal, natural gas, petroleum, solar or biomass sources) to make power, and are responsible for roughly 80% of global electricity production (Figure 3.5).

> ***Approximately 90% of global power generation*** *is water intensive. Water is used directly for hydropower generation as well as for all forms of thermal power generation schemes.*

Increasing ambient water temperatures and changes in overall water availability create risks for the power sector. Power plants have had to shut down because of lack of water for cooling purposes or because of high water temperatures; droughts are threatening the hydropower capacity of many countries; and several reports conclude that water availability could be a constraint for the expansion of the power sector in many emerging economies, especially in Asia (IEA, 2012*a*; Bloomberg, 2013; Sauer et al., 2010).

Almost 1.3 billion people did not have access to electricity in 2010 (Table 1.1). Although access differs significantly across regions, the majority of the unserved population resides in LDCs and sub-Saharan Africa in particular (Figure 3.6).

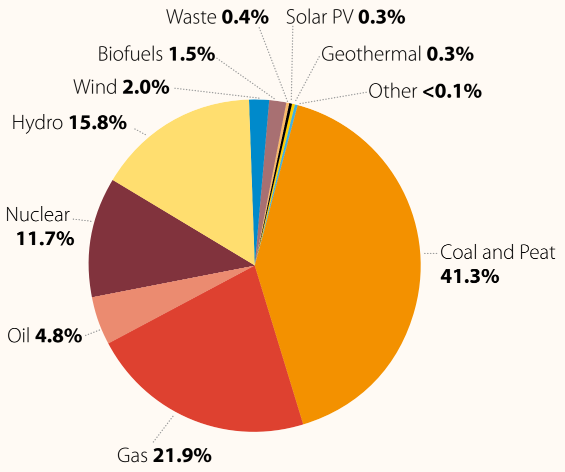
FIGURE 3.4 **Global ethanol production by feedstock**



Source: OECD/FAO (2010, fig. 4.5, p. 87). OECD-FAO Agricultural Outlook 2010–2019 © OECD.

Globally, electricity demand is expected to grow by roughly 70% by 2035. This growth will be almost entirely in non-OECD countries, with China and India accounting for more than half that growth. As shown in Table 3.1 and Figure 3.7, the greatest increases in the power generation mix in both OECD and non-OECD countries are expected to come from renewables. Hydropower is expected to account for the largest portion of the renewable increase in non-OECD countries, whereas wind is predicted to dominate in the OECD. In the absence of sturdy energy policies, the capital cost of the plant is by far the most important driver in the evolution of nuclear power and renewables. Relative costs, which are also influenced by government policies, are the primary driver of the projected changes in the types of fuels and technologies used to generate power (IEA, 2012*a*).

FIGURE 3.5 **World electricity generation by source of energy as a percentage of world electricity generation, 2011**



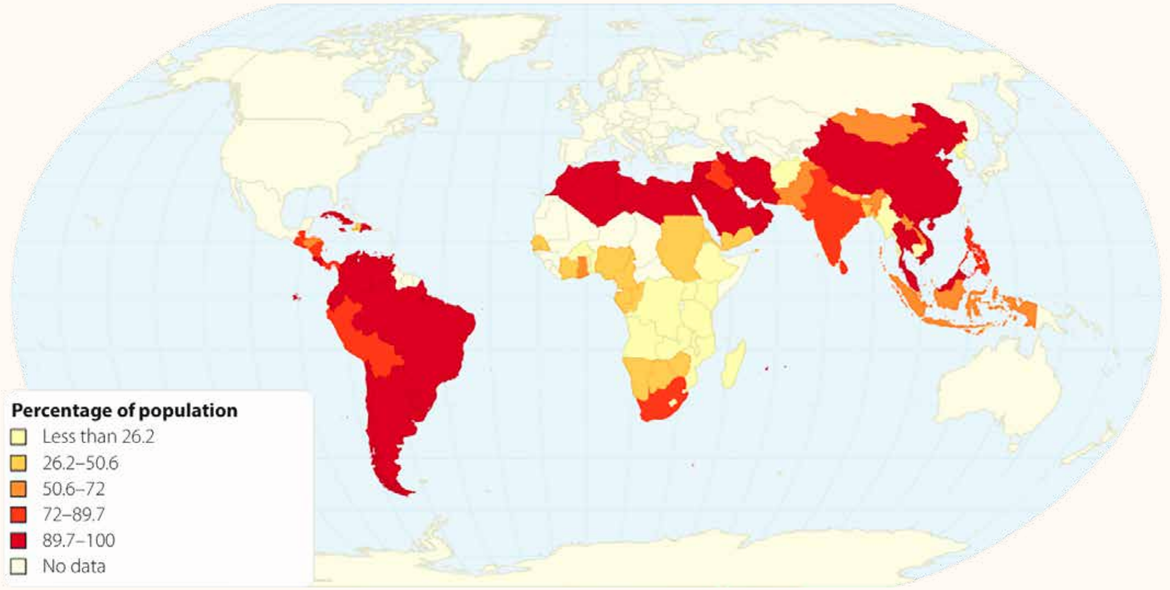
Note: PV, solar photovoltaic.
Source: WWAP, from data in IEA (2013).

The following sections examine water-related impacts and implications of the main forms of electricity generation and provide an outlook of projected future growth trends that will determine the pressures on water resources.

3.3.1 Thermal power

With a direct heat transferring capacity roughly four times greater than air, water is a much more effective coolant. The thermal power sector is a large user of water; in Europe, it is responsible for 43% of total freshwater withdrawals (Rübbelke and Vögele, 2011) and accounts for more than 50% national water withdrawals in several countries (Eurostat, 2010). The thermal power sector is also the single largest user of water in the USA, responsible for nearly half of all water withdrawals, ahead of even agriculture (Kenny et al., 2009). In China, water

FIGURE 3.6 **Access to electricity in developing countries as a percentage of the population, 2011**

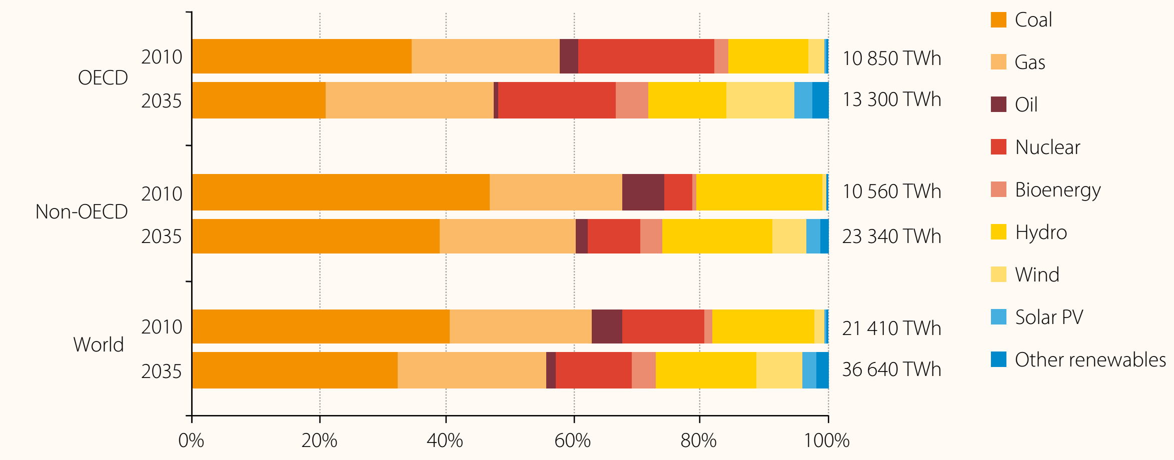


Source: ChartsBin.com (http://chartsbin.com/view/10471, based on source cited therein [original data from IEA World Energy Outlook statistics at http://www.iea.org/stats/index.asp]) (Accessed Oct 2013) and updated with data from the IEA World Energy Outlook 2013 Electricity Access Database (http://www.worldenergyoutlook.org/media/weowebsite/energydevelopment/WEO2013Electricitydatabase.xlsx) for India and Nicaragua.

withdrawals for power plant cooling exceed 100 billion m^3 annually, which is more than 10% of the national cap (700 billion m^3) (Bloomberg, 2013). In developing countries, relative water use by the power sector is generally lower, and by the agriculture sector is generally higher.

FIGURE 3.7

Share of electricity generation by source and region in the New Policies Scenario



Note: See Box 3.1 for an explanation of the New Policies Scenario. PV, solar photovoltaic.
Source: IEA (2012a, fig. 6.2, p. 183). World Energy Outlook 2012 © OECD/IEA.

TABLE 3.1

Electricity generation by source and scenario (TWh)

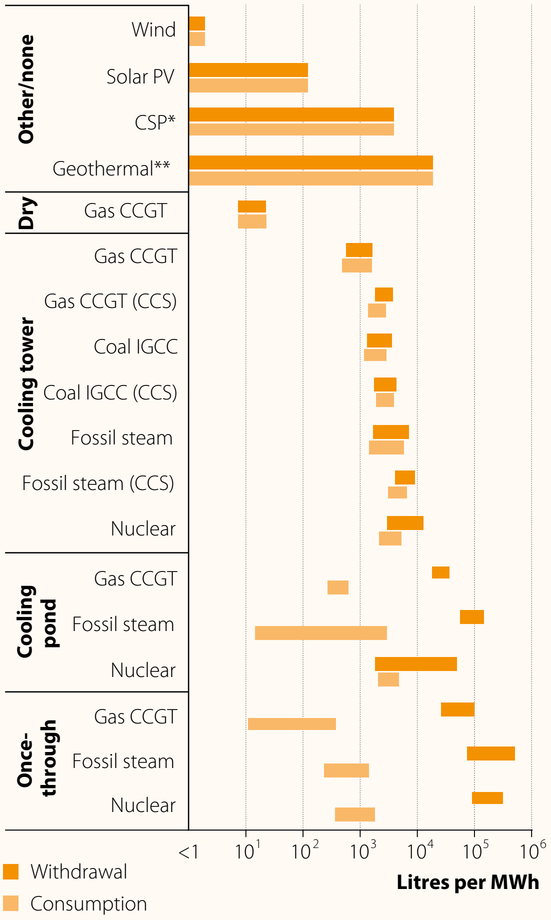
			New Policies		**Current Policies**		**450 Scenario**	
	1990	**2010**	**2020**	**2035**	**2020**	**2035**	**2020**	**2035**
OECD	**7 629**	**10 848**	**11 910**	**13 297**	**12 153**	**14 110**	**11 470**	**12 153**
Fossil fuels*	4 561	6 600	6 629	6 401	6 981	7 948	5 931	3 328
Nuclear	1 729	2 288	2 318	2 460	2 299	2 240	2 392	2 982
Hydro	1 182	1 351	1 486	1 622	1 474	1 578	1 521	1 730
Other renewables	157	609	1 477	2 813	1 400	2 343	1 627	4 112
Non-OECD	**4 190**	**10 560**	**16 325**	**23 340**	**17 040**	**26 255**	**15 026**	**19 595**
Fossil fuels*	2 929	7 847	11 163	14 528	12 167	18 882	9 522	7 159
Nuclear	283	468	1 125	1 906	1 099	1 668	1 209	2 986
Hydro	962	2 079	3 027	4 054	2 916	3 771	3 137	4 532
Other renewables	15	166	1 010	2 851	858	1 934	1 159	4 918
World	**11 819**	**21 408**	**28 235**	**36 637**	**29 194**	**40 364**	**26 497**	**31 748**
Fossil fuels*	7 490	14 446	17 793	20 929	19 148	26 829	15 453	10 487
Nuclear	2 013	2 756	3 443	4 366	3 397	3 908	3 601	5 968
Hydro	2 144	3 431	4 513	5 677	4 390	5 350	4 658	6 263
Other renewables	173	775	2 486	5 665	2 259	4 277	2 785	9 031

** Includes coal-, gas- and oil-fired generation.*
Note: See Box 3.1 for an explanation of the scenarios.
Source: IEA (2012a, table 6.2, p. 182). World Energy Outlook 2012 © OECD/IEA.

Several factors determine how much cooling water is needed by thermal power plants, including the fuel type, cooling system design and prevailing meteorological conditions. However, efficiency is often the main factor that drives water requirements: the more efficient the power plant, the less heat has to be dissipated, thus less cooling is required (Delgado, 2012). Older power plants tend to be less efficient and thus consume more water (using the same cooling system under similar meteorological conditions).

FIGURE 3.8

Water use for electricity generation by cooling technology



** Includes trough, tower and Fresnel technologies using tower, dry and hybrid cooling, and Stirling technology. ** Includes binary, flash and enhanced geothermal system technologies using tower, dry and hybrid cooling.*
Notes: Ranges shown are for the operational phase of electricity generation, which includes cleaning, cooling and other process related needs; water used for the production of input fuels is excluded. Fossil steam includes coal-, gas- and oil-fired power plants operating on a steam cycle. Reported data from power plant operations are used for fossil-steam once-through cooling; other ranges are based on estimates summarized in the sources cited. Solar PV, solar photovoltaic; CSP, concentrating solar power; CCGT, combined-cycle gas turbine; IGCC, integrated gasification combined-cycle; CCS, carbon capture and storage. For numeric ranges, see http://www.worldenergyoutlook.org.
Source: IEA (2012a, fig. 17.4, p. 510, from sources cited therein). World Energy Outlook 2012 © OECD/IEA.

[**See Chapter 21** (Volume 2) for the case study 'Water use efficiency in thermal power plants in India'.]

For power plants with similar efficiency levels, the cooling system used will determine how much water is required. The three most prevalent cooling methods are open-loop, closed-loop and dry cooling (hybrid wet-dry systems exist, but are not widely used). Open-loop, or once-through, cooling withdraws large volumes of surface water, fresh and saline, for one-time use and returns nearly all the water to the source with little being consumed by evaporation (Figure 3.8). Closed-loop cooling requires less water withdrawal, as the water is recirculated through use of cooling towers or evaporation ponds, leading to much higher water consumption (Table 3.2) (Stillwell et al., 2011).

Dry cooling does not require water, but instead cools by use of fans that move air over a radiator (similar to those in automobiles). Power plant efficiency is lower, and this option is often the least attractive economically. While dry cooling is less effective in warmer and dryer climates, such installations do operate in warm and dry areas, including China, Morocco, South Africa and south-western USA, because these systems offer resilience against drought, but have parasitic losses on power plant output. It has been estimated that cost reductions of 25% to 50% are needed for air cooled condensers (ACC) to become economically competitive in most regions of the world (Ku and Shapiro, 2012).

The volatility of price fluctuations of the three main fuels for thermal power generation – coal, natural gas and oil – renders the projection of future trends in plant development and related fuel consumption problematic. The future energy mix is likely to be determined by factors such as developments in the exploration and production of unconventional oil and gas, the economic implications of these developments, and their impact on the market price of fuels. The future of unconventional gas is itself uncertain, according to the IEA (2012*a*, p. 125): 'the prospects for unconventional gas production worldwide remain uncertain and depend, particularly, on whether governments and industry can develop and apply rules that effectively earn the industry a "social licence to operate" within each jurisdiction, so satisfying already clamorous public concerns about the related environmental and social impacts' (Box 3.2).

Globally, electricity demand is expected to grow by roughly 70% by 2035. This growth will be almost entirely in non-OECD countries.

In spite of the uncertainties, coal is expected to remain the backbone fuel for electricity generation globally through to 2035 (Figure 3.7). Although its use for this purpose will continue to rise in absolute terms, its share in the total generation is expected to fall while the share of gas increases slightly (IEA, 2012*a*). Oil-fired power generation is also likely to diminish, due in part to increased competition for oil from the transportation sector.

3.3.2 Nuclear power

As nuclear power generation relies on the same cooling technologies as those described above for thermal power (nuclear *is* a form of thermal power), the immediate water-related impacts are similar. Nuclear output is expected to grow in absolute terms, driven by expanded generation in China, Korea, India and Russia, but its share in the global electricity mix is expected to fall slightly over time (Table 3.3; Figure 3.7) (IEA, 2012*a*). In Canada and the USA, the competitiveness of nuclear power is being challenged by the growth of relatively inexpensive natural gas.

3.3.3 Hydropower

Although hydropower generation is a major water user, most of the water used is returned to the river

TABLE 3.2 **Thermal power plant cooling system advantages and disadvantages**

Cooling system	Advantages	Disadvantages
Once-through [open-loop]	Low water consumption Mature technology Lower capital cost [Highest performance]	High water withdrawals [with risk of impingement and entrainment of aquatic life] Impact on ecosystem Exposure to thermal discharge limits
Wet tower [closed-loop]	Significantly lower water withdrawal than once-through Mature technology [High performance]	Higher water consumption than once-through Lower power plant efficiency [slightly lower performance than once-through] Higher capital cost than once-through [Thermal plumes]
Dry	Zero or minimal water withdrawal and consumption	Higher capital cost relative to once-through and wet tower Lower plant efficiency, particularly when ambient temperatures are high [hot, dry days] Larger land area requirements
Hybrid [wet-dry]	Lower capital cost than dry cooling Reduced water consumption compared with wet tower No efficiency penalty on hot [wet] days Operational flexibility	Higher capital cost than wet tower Limited technology experience

Source: Adapted from IEA (2012a, table 17.2, p. 509, from source cited therein). World Energy Outlook 2012 © OECD/IEA.

***Hydroelectricity** is currently the largest renewable source for power generation in the world, meeting 16% of global electricity needs in 2010*

downstream of the plant once it has run through the turbines or when the reservoir has been filled. Data on water consumption by hydropower are widely inconsistent (WWAP, 2012, box 2.1) and initiatives are exploring the need and methods for apportionment of the consumed water to the various services of the reservoir. The amount of water consumed via seepage and evaporation is determined by climate, physical characteristics of the reservoir, and allocations to other uses, which are site-specific and variable.

'Run-of-the-river' hydroelectric plants consume minimal water. They return temporarily diverted water to the running water source, and do not require reservoirs. At the moment, however, they are too small in scale to supply large amounts of energy (Glassman et al., 2011) and are therefore best suited to provide power at the community level.

Beyond electricity generation, hydropower, and more specifically reservoirs, can also provide storage for dry spells, and they support flood management, navigation and recreation. Problems can arise due to the different timings throughout the year when releases of water are required for different purposes. Large-scale hydroelectric plants around the world have been criticized for a number of reasons, including damage to the environment and biodiversity, loss of cultural and historical sites, and social disruption (Glassman et al., 2011) (see Section 9.2.1 for more on the impacts of hydropower on ecosystems).

[**See Chapters 19 and 23** (Volume 2) for the case studies 'Hydropower development in Eastern Herzegovina: The Trebišnjica Multipurpose Hydrosystem' and 'The role of hydroelectric power stations in the aftermath of the Great East Japan Earthquake', respectively.]

Hydroelectricity is currently the largest renewable source for power generation in the world, meeting 16% of global electricity needs in 2010 (IEA, 2012a) (Figure 3.5). The recent rate of growth in electricity generation from additional hydro capacities has been similar to that of all other renewables combined (Figure 3.9) (IEA, 2012*b*). In 2010,[11] the global

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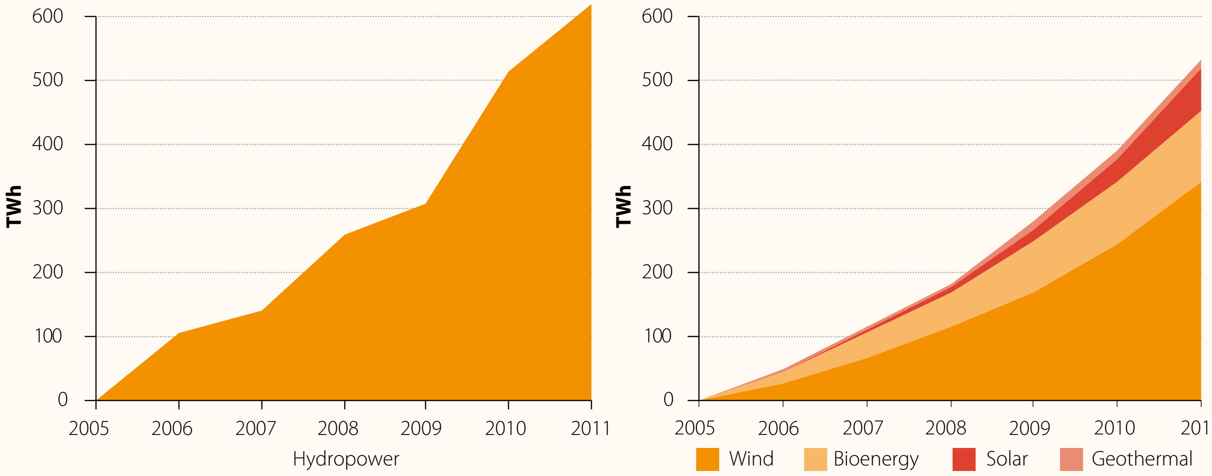
[11] The most recent single year for which such data were available at the time of writing this report.

3.9 FIGURE

Electricity generation from recent additions to hydropower and other renewables



Source: IEA (2012b, fig. 3, p. 12, from source cited therein). Technology Roadmap: Hydropower 2012 © OECD/IEA.

production of hydroelectricity was estimated to have increased by more than 5% (IRENA, 2012*b*).

Hydropower, when associated with water storage in reservoirs, can store energy over weeks, months, seasons or years. Because spinning turbines can be ramped up more rapidly than any other generation source, hydropower (and pumped storage) can contribute to the stability of the electrical system by providing the full range of ancillary services required for the high penetration of variable renewable energy sources, such as wind and solar (IRENA, 2012*b*).

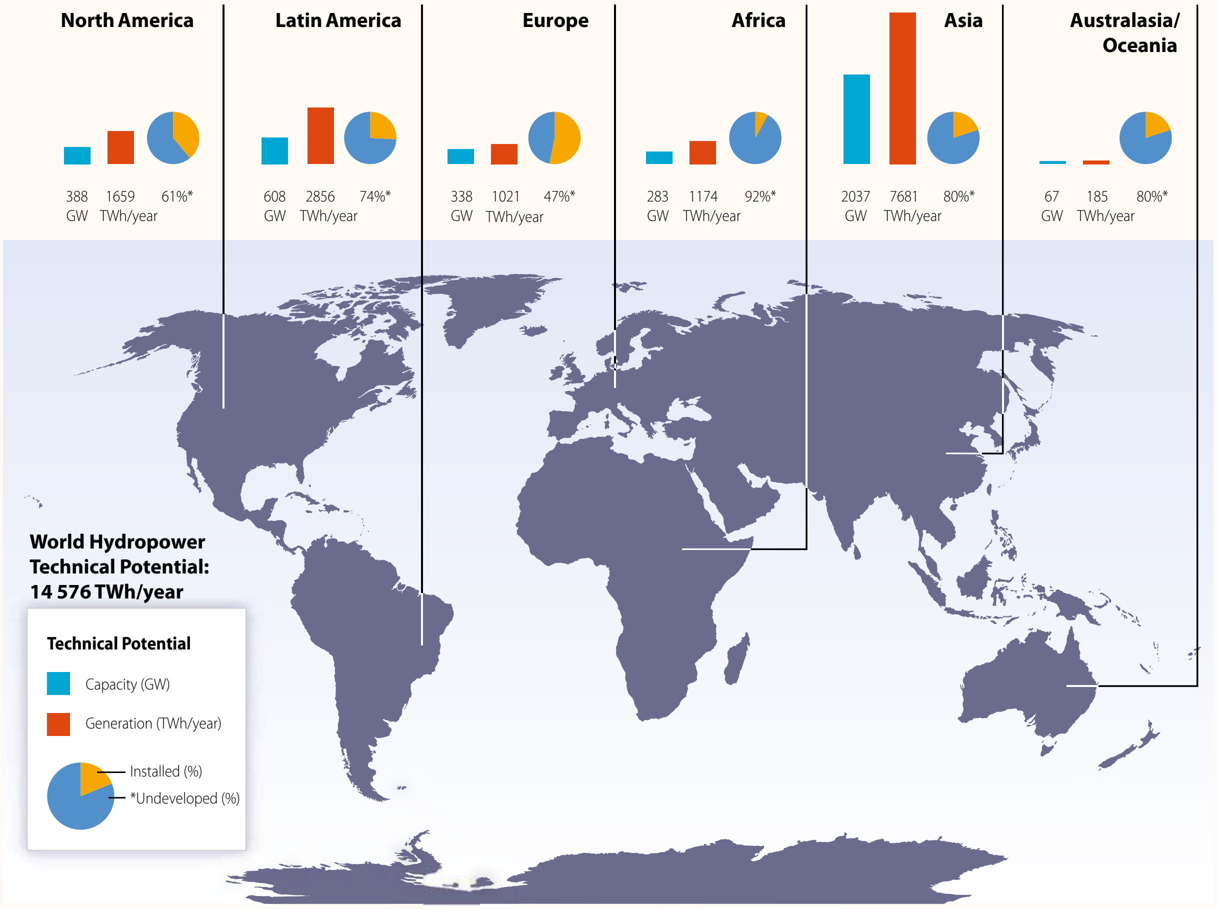
Pumped storage hydroelectricity is a type of generation used by some power plants. These plants make use of low-cost off-peak energy to adjust to variations in demand and to balance the load. They are a net consumer of energy. They draw electricity from the grid to lift the water up, then return most of the water later, with a round-trip energy efficiency of 70% to 85% (IEA, 2012*b*). It has been estimated that more than 127,000 MW of pumped storage capacity was operating worldwide in 2009, and this was expected to grow 60% through 2014 (Montoya, 2009). Pumped storage currently represents 99% of on-grid electricity storage (EPRI, 2010).

According to Kumar et al. (2011), the percentage of undeveloped technical potential for hydropower is highest in Africa (92%), followed by Asia (80%), Australasia/ Oceania (80%) and Latin America (74%) (Figure 3.10). However, only about two-thirds of estimated total technical potential is believed to be economically feasible (Table 3.3) (Aqua-Media International Ltd, 2012).

Hydropower's share in total electricity generation is expected to remain around 15% through 2035 (IEA,

FIGURE 3.10

Regional hydropower technical potential in terms of annual generation and installed capacity, and percentage of undeveloped technical potential in 2009



Source: Kumar et al. (2011, fig. 5.2, p. 445, based on source cited therein). © IPCC.

> ***Wind and solar PV** consume negligible amounts of water, yet they provide an intermittent service that needs to be compensated for by other sources of power (which do require water) to maintain load balances on larger grids*

2012*a*), keeping pace with the overall growth rate of power generation. Nearly 90% of the expected increase in hydropower production between 2010 and 2035 would be in non-OECD countries, where the remaining potential is higher and growth in electricity demand is strongest. Most incremental increases in hydropower output are expected to come from large projects in emerging economies and developing countries in Asia and Latin America, notably in China, India and Brazil (IEA, 2012*a*). In Asia and particularly in Africa, lack of financing and of operational capacity, combined with political and market risks, create major challenges to hydropower development (Chapters 11, 14). Uncertainty remains with respect to how various social and environmental issues may affect the rate of hydropower development in these regions.

3.3.4 Solar and wind power

Broadly, there are two primary categories of solar technologies. One, solar photovoltaic (PV), converts solar energy directly into electricity. Like wind, solar PV generally consumes minimal water (Figure 3.8), mainly in the production stage and during cleaning and maintenance. The other, concentrated solar power (CSP), commonly known as 'solar thermal', concentrates solar rays to produce steam to power turbines.

Using the same type of cooling system (and assuming today's generation of technology and cleaning frequency), CSP consumes approximately five times more water per unit energy than a gas-fired power plant, two times more than a coal-fired plant and 1.5 times more than a nuclear plant (Glassman et al., 2011). There are efforts to reduce this need for water in many aspects of solar thermal systems, ranging from mirrors to fluids and thermal storage. Dry cooling (Section 3.3.1) is already being implemented in some CSP power plants around the world, including the Ain Beni Mathar CSP-CC power plant in Morocco (Abengoa Solar, n.d.).

During the period 2000–2010, electricity generation from wind grew by 27% and from solar PV by 42% per year on average (IEA, 2012*a*). While hydropower and geothermal electricity produced at optimal sites are still among the cheapest ways of generating electricity, the levelized[12] cost of electricity is declining for wind, solar PV, CSP and some biomass technologies (IRENA, 2013). Wind and solar power are expected to continue expand rapidly over the next 20 years (IEA, 2012*a*).

3.3 TABLE **Economically feasible hydropower potential, installed capacity and power generation by region**

	Economically feasible hydropower potential (GWh/year)	Installed hydrocapacity (MW)	Hydro generation in 2011 or average/most recent (GWh/year)
Africa	842 077	25 908	112 163
Asia	4 688 747	444 194	1 390 800
Australasia/Oceania	88 700	13 327	39 394
Europe	842 805	181 266	531 152
North America	1 055 889	140 339	681 496
South America	1 676 794	140 495	712 436
World	**9 195 041**	**975 528**	**3 467 440**

Source: WWAP, with data from Aqua-Media International Ltd (2012).

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[12] The 'levelized cost of energy' is the constant price per unit of energy that causes the investment to break even.

In a study comparing various sources of renewable energy in terms of environmental and social impacts, wind power turned out to be the most sustainable, mainly because of its low GHG emissions and water consumption (Evans et al., 2009). Wind and solar PV consume negligible amounts of water, yet they provide an intermittent service that needs to be compensated for by other sources of power (which *do* require water) to maintain load balances on larger grids. Climate information is critical for the safety and basic operations of these renewable energy sources (as well as hydropower) to ensure consistency and cost-effectiveness of power generation.

3.3.5 Geothermal power

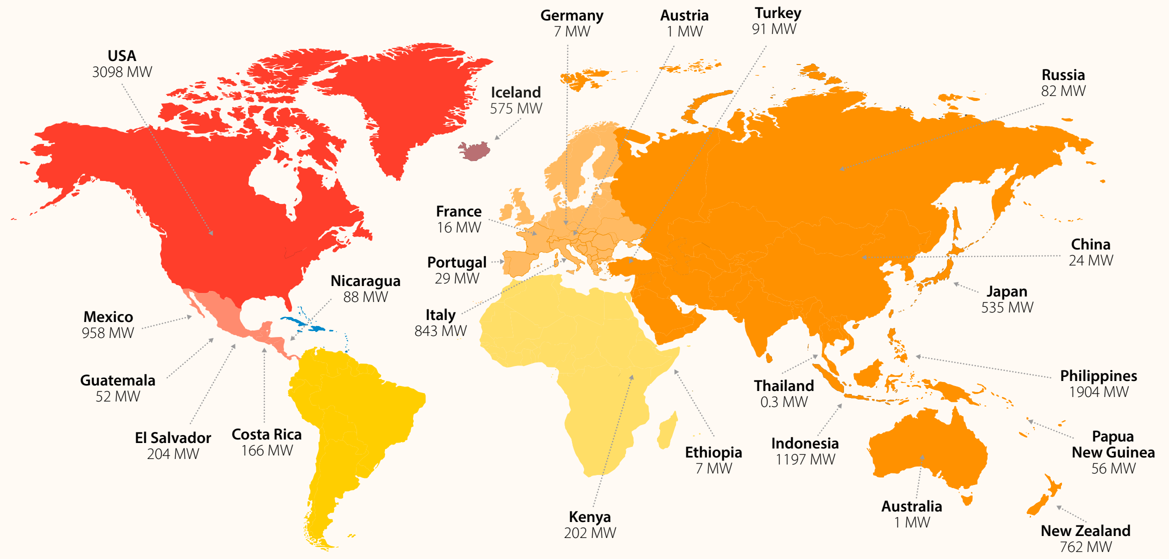
Although geothermal power plants have been reported to generally use and consume less water per kilowatt-hour of lifetime energy output than other electric power generation technologies (Clark et al., 2010), actual water requirements are highly variable from site to site (Figure 3.8) based on well depth and technology used, among other factors.

The relative growth in wind and solar energy has in recent years outstripped that of geothermal energy, reflecting strong investment for research and development in those sectors. In contrast to wind and solar power plants, however, geothermal power plants are well suited to producing a balanced and highly efficient electrical base load (van der Gun et al., 2012).

[**See Chapters 22 and 29** (Volume 2) for the case studies 'A science-based tool for integrating geothermal resources into regional energy planning in Umbria, Italy' and 'The use of and prospects for geothermal energy in Turkey'.]

Considering the average thermal gradient of Earth, the potential for developing low to medium temperature geothermal resources (from a few degrees above ambient temperature to 150°C) for direct thermal uses is present in most parts of the world. High temperature resources capable of electricity generation (ranging from 150°C to more than 300°C) being linked to crustal thermal anomalies are rarer. They have been identified in some 90 countries, and quantified records of their utilization exist for 79 countries. Geothermal electricity is generated in 24 countries, providing a significant proportion (5% to 26%) of the national electricity balance in nine of them. Ten developing countries are among the top 16 countries in geothermal electricity production (Bertani, 2012) (Figure 3.11).

3.11 FIGURE **Worldwide installed capacity for geothermal electricity in 2010**



Note: Worldwide total: 10.9 GW.
Source: Bertani (2012, fig. 2, p. 3).

[**See Chapter 25** (Volume 2) for the case study 'The role of geothermal energy in Kenya's long-term development vision'.]

Geothermal energy for both direct thermal uses (district heating and others) and for power generation is underdeveloped and its potential is greatly underappreciated. It is climate independent, produces minimal to near-zero GHG emissions, does not consume water, and its availability is infinite at human time scales. In 2010, the annual worldwide use of geothermal energy was reported to be 67 TWh for electricity and 122 TWh for direct use (Fridleifsson, 2012). Although this is a marginal quantity on the global scale (Figure 3.5), geothermal energy can make a substantial contribution to energy supply at the local or national levels. It is considered possible to increase the installed worldwide geothermal electricity capacity from the current 10 GW to 70 GW with present technology, and to 140 GW with enhanced technology (Fridleifsson et al., 2008).

A recent study consolidating decades of archived geological information in the USA shows that geothermal energy could offer 3,000 GW of added power – approximately 10 times the capacity of the country's coal power plants (Blackwell et al., 2011).

3.3 **BOX**

The water-related challenges of coal-fired power stations in Western China

In the water-scarce western regions of China, new industries and power stations secure cooling water from local lakes and rivers, drawing down groundwater aquifers and building reservoirs to capture rainwater, all of which disrupt water supplies to other local users and lead to unsustainable water use. Because of such activities in Inner Mongolia it has been reported that the water table has dropped and grasslands such as Xilingol have become unproductive. The Wulagai Wetland has dried up significantly (Larson, 2012). In such cases, the sheer volumes of water abstracted for cooling, even though mainly non-consumptive, can have a significant impact on water levels and other users in regions of growing water scarcity. The most recent Chinese Five Year Plan (2011–2015) calls for the creation of 14 large coal industry bases across Western China, to include coal mines and coal-fired power plants (Larson, 2012).

Source: James Winpenny, WWAP.

3.4 Energy policy implications for water

As described throughout this chapter, water can play either a beneficial or a detrimental role in the viability of energy production options. It is therefore vital to take account of the water implications of different options when developing energy policy. Changes to the energy mix are not occurring in the same way globally. Trends can be differentiated for the power sector and transportation fuels sector. The energy mix is constantly evolving, determined in large part by national energy policy, which is itself influenced by markets, technologies and (often to a lesser extent) social and environmental concerns.

In the transportation fuels sector, much of the world is moving away from conventional petroleum-based fuels (petrol and diesel, relatively water-lean to produce). Many nations are selecting more water intensive options, such as unconventional fossil fuels (from hydraulic fracturing, coal-to-liquids or oil sands), biofuels and electricity. Even electric powered transportation is water intensive because of water requirements at the power plant. The USA initiated a major policy priority in 2007 of moving towards increased use of biofuels, with additional policy support for gas and liquids produced from hydraulic fracturing, both of which are relatively water intense. While the EU is revisiting its biofuel policies, biofuels remain a priority and a non-negligible portion of the fuel mix in Europe.

In the power sector, some regions are moving towards more water intensive options while others are moving towards less water intensive choices as different nations pursue different paths. Planned and possible phase-outs and reductions in nuclear power may lead to more or less water intensive alternatives, including renewables and natural gas. Much of the Asia-Pacific region and South America is moving towards a large build-up of hydroelectric power (Chapters 11 and 13). New reservoirs might increase consumption (due to increased evaporation), but might also increase water availability for other uses because of large-scale storage capacity. China is moving aggressively to ramp up its coal production, which can be water intensive at the power plant and in the mining process (Box 3.3). China, along with India and the Middle East, is also moving towards increased nuclear power production. The USA is moving away from coal towards natural gas and wind and solar energy, which will reduce the water intensity of its power production.

3.4.1 Competition over scarce water supplies: The emerging challenge of thermal power generation

The abstraction of water for cooling purposes by thermal power stations is high and rising across many regions and countries of the world. This is especially so in the countries of Europe and in China, India and the USA. This has triggered concern in the US Administration (US GAO, 2009). Concern is also spreading about the compatibility of China's energy plans with its water availability (IEA, 2012*a*, ch. 17; Larson, 2010, 2012).

A common view is that raw water drawn for thermal power and industrial cooling purposes is non-consumptive, because nearly all of it is returned to public water bodies for use by other sectors. For the most common forms of cooling (once-through/open-loop), large volumes of water are abstracted, but only a small percentage is actually consumed (Section 3.3.1).

Concerns about the use of water by thermal power stations centre on several key issues. First, the release of large volumes of heated water from open-loop power plants into natural watercourses affects fish and other wildlife, which raises environmental concerns (Section 9.2.4). Second, the abstraction, transport, storage and release of the cooling water can be highly disruptive for other local water users. Third, for the alternative, closed-loop thermal power stations, consumptive use is much higher – 50% or more (Kenny et al., 2009). This cooling technology is spreading, especially in water scarce areas.

The water footprint of thermal power generation extends to its main source of primary energy – whether coal, oil or gas.[13] For countries such as China and India, where a high proportion of electricity is from coal-fired power stations (80% in China), the water required for coal mining operations (Figure 3.1) is a major additional factor to be considered.

> ***In the transportation fuels sector,*** *much of the world is moving away from conventional petroleum-based fuels (petrol and diesel, relatively water-lean to produce). Many nations are selecting more water intensive options, such as unconventional fossil fuels (from hydraulic fracturing, coal-to-liquids or oil sands), biofuels and electricity. Even electric powered transportation is water intensive because of water requirements at the power plant.*

It is unrealistic and unfair to expect all the adjustment to fall on a single water user, such as thermal power generation. Actions by other major water users are necessary too. As described in Part 2 of this report, there is major scope for reducing the water footprints of agriculture, industry and cities as well. However, with energy (and thermal power in particular) expected to be the fastest growing water demand sector over the next few decades, it is imperative that the water implications of energy options such as thermal power are taken into consideration.

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[13] Nuclear power is a special case.

CHAPTER

4

Data challenges and opportunities

WWAP | Richard Connor, Arjen Y. Hoekstra and Engin Koncagül

This chapter focuses on data issues directly related to the water–energy nexus.[14]

Generally speaking, aggregated data on energy are available with much greater fidelity and abundance than are data on water.

Top-level annual estimates for energy consumption by fuel exist at the national level for most countries, allowing for informed decision-making in terms of energy policy as well as for financial, economic, environmental and welfare policy, among others. In addition, because some forms of energy – namely oil, gas and coal – have a global market, trade statistics are available that can be used to track global production and consumption by country. The World Bank and IEA track top-level statistics based on energy trade, as does the British Petroleum Statistical Review. No such market-related parallel exists for water.

In the industrialized countries, data are also available on a frequently updated basis (weekly for petroleum, monthly for electricity and other forms of energy) for energy production and consumption according to fuel type and end use. This provides these countries with a net competitive advantage over developing countries that may not have the governmental structures or capacities necessary for such systematic data collection and analysis. Even where energy data are collected in great detail, however, the resolution and extent of the data are not aligned with water data. From a water management point of view, it is important to know whether, for instance, desalination is done using fossil fuels or solar energy.

For water resources, monitoring availability and use represents an immense and ongoing challenge, especially given their variable distribution over time and space

For water resources, monitoring availability and use represents an immense and ongoing challenge, especially given their variable distribution over time and space. Traditional statistics assessing the relative water intensity of major water uses (domestic, industry, agriculture) are often unsatisfactory when one is interested in the final goal of allocating water resources to different sectors. This is especially unsatisfactory regarding energy, which appears to account for 75% of all industrial withdrawals (Section 2.2). There are often too few metrics upon which to make informed decisions or to track any outcomes of water productivity improvement measures. In many cases, relevant water datasets may be non-existent, out of date, limited or filled with errors. And when available, water use statistics are generally limited to gross water withdrawals, while it is often more relevant to know the net water consumption.

Lack of data puts water resources management at a political disadvantage in terms of priority decision-making. While energy may be perceived as 'big business' (Section 1.3.2), the central role of water in socio-economic development remains under-acknowledged (WWAP, 2012). As a result, many of the decisions made and implementation mechanisms adopted with respect to energy (e.g. improved efficiency, economic growth, enhanced service coverage or benefitting the impoverished) fail to take proper account of the impact of these actions on water resources or the different benefits to other water users.

Water and energy use accounts offer a limited means for understanding the critical links between the water and energy domains. An often-overlooked issue in the water-for-energy debate is whether water requirements are expressed per unit of gross or net energy output. For example, existing agricultural water use statistics make it hard to determine how much water is actually used

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[14] For a detailed discussion of data availability on water resources and their use, see WWAP (2009, ch. 13 and 2012, ch. 6).

for the production of biofuel crops, where the energy input in production is often substantial compared with the energy output, so the water footprint per unit of net energy output can easily be a multiple of the water footprint per unit of gross energy output (Gerbens-Leenes et al., 2009).

Decisions about water and energy allocation, production and distribution between different users and uses have important social and gender equality implications, and impact on the resources available at community levels. Monitoring progress requires the generation and analysis of gender-disaggregated data, which considers not only the existence of differences between men and women, but also the causes and impacts of these differences.

The coordinated approaches to water and energy called for throughout this report require the generation and harmonization of data concerning the supply and use of water and energy production. A more detailed set of water accounting statistics describing different water uses within sectors, including energy, would facilitate decision-making and help ensure that water resources are allocated to the most appropriate uses. Although estimating water consumption for different types of energy production can be quite challenging, time consuming and error-prone, this knowledge is fundamental to ensuring energy security where water availability can be a limiting factor.

4.1 Key indicators relating to water and energy

Information forms the basis of the United Nations *World Water Development Report*. Because raw data can be viewed from varying perspectives and interpreted subject to varying perceptions, indicators are indispensable tools for establishing a common ground when examining status, measuring progress and planning targets. While data availability and quality remain a concern for water professionals and decision-makers in associated sectors, the importance of indicators based on best possible data cannot be overestimated.

This fifth edition of the Report presents a Data and Indicators Annex (DIA) of 41 indicators (see the summary listing in this chapter and the Annex [in Volume 2] for the full entries of charts and tables). These indicators have been selected because they benchmark actual conditions and highlight trends related to water and energy, and thus enrich the Report. Taken together, the indicators also serve to present complex information in a meaningful but understandable manner for both decision-makers and other stakeholders, and it is hoped they will allow for informed, rational decisions to be made.

***Top-level annual estimates for energy consumption** by fuel exist at the national level for most countries, allowing for informed decision-making in terms of energy policy*

Data and Indicators Annex of the WWDR 2014

Demographics
I-1: Demographic projections
I-2: Urban and rural populations by development group (1950–2050)

State of freshwater resources
I-3: Total actual renewable water resources per capita (2011)
I-4: Total actual renewable water resources per capita: Trends and projections
I-5: Annual average monthly blue water scarcity in the world's major river basins (1996–2005)

Water demand
I-6: Water withdrawal by sector (around 2006)
I-7: Water demand at the global level and in country groups (Baseline Scenario 2000 and 2050)

Human well-being
I-8: Population using solid fuel for cooking and without access to electricity, improved water and sanitation in a selection of countries
I-9: Access to improved drinking water (1990–2011)

Energy
I-10: World total primary energy supply by source
I-11: World primary energy demand: Trends and projections
I-12: Trends in electricity generation in the world and in selected countries (1971–2012)
I-13: Trends in world electricity generation by energy source
I-14: Trends in electricity consumption (2000–2011)

Lack of data puts water resources management at a political disadvantage in terms of priority decision-making

I-15: Share of people without electricity access in developing countries (2011)
I-16: Global electricity access rate: Trends and projections
I-17: Energy consumption per capita (2010)
I-18: Trends in electricity consumption per capita (2000–2011)

Dams and hydropower

I-19: Use of dams by purpose
I-20: Total dam capacity per capita by region (around 2010)
I-21: Hydropower: Technical potential and installed capacity by region (2009)
I-22: Trends in hydropower production in selected regions and countries

Water <-> Energy

I-23: Global water use for energy production by scenario
I-24: Energy requirement to deliver 1 m^3 water safe for human consumption from various water sources
I-25: Indicative energy use of municipal water and wastewater services
I-26: Energy requirements and cost implications of desalination by technology
I-27: Global cumulative contracted versus commissioned daily desalination capacity (2013)
I-28: Power consumption trends in seawater reverse osmosis desalination (1985–2009)
I-29: Water footprint of energy generation by fuel
I-30: Water use for electricity generation by cooling technology

ISO certification

I-31: Trends in ISO 14001 certification (1999–2012)
I-32: ISO 50001 certification on energy management

Geothermal electricity

I-33: Trends in geothermal electricity output (2000–2011)
I-34: Worldwide installed capacity for geothermal electricity generation (2010)

Bioenergy

I-35: Global trends in ethanol and biodiesel production (1975–2010)
I-36: Indicative yields and water requirements for some major biofuel crops
I-37: Global total final energy consumption versus share of renewable energy

Water and energy in national policy

I-38: The importance of water for energy
I-39: Perceived change over the past 20 years in the importance of water for energy
I-40: National energy policy/strategy/plan with water resources management component
I-41: Infrastructure development and mobilizing financing for energy/hydropower

PART 2 THEMATIC FOCUS

CHAPTERS

5. Infrastructure
6. Food and agriculture
7. Cities
8. Industry
9. Ecosystems

CHAPTER

5 Infrastructure

World Bank

Diego J. Rodriguez and Anna Delgado

5.1 Infrastructure and development

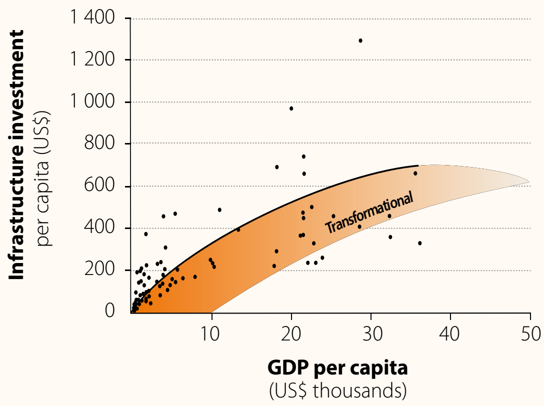
Between 2013 and 2015, annual economic growth is estimated to be around 6% in developing countries and around 2% in higher-income countries (World Bank, 2013*a*). As economies grow and diversify, they experience competing demands for water to meet the needs of more municipal and industrial uses, as well as agriculture. However, many people in the world still lack access to basic water and energy services (Section 1.1). Closing the energy gap could generate additional pressures on water resources given that water is needed for fuel extraction, for cooling and other processes in thermal power plants, and for turning turbines in hydropower plants (Chapter 3). Moreover, climate change can exacerbate already stressed energy and water scenarios through events such as extreme weather conditions and prolonged drought periods (Section 12.3).

A lack of adequate infrastructure undermines living standards and limits the growth potential of developing countries (Rodriguez et al., 2012), yet infrastructure expansion often comes at the expense of the local environment and has complicated responses to long-term challenges, including climate change (Toman et al., 2011). Planning, building and maintaining infrastructure is a real challenge, as it requires lump-sum up-front outlays with a high risk of lock-in effects. However, much research indicates a clear positive linkage between infrastructure services (including water and energy) and economic development, poverty reduction and improvement of broader development goals, such as the MDGs (Figure 5.1) (World Bank, 2004). The relationship between infrastructure and development is complex, as more infrastructure does not necessarily entail more growth. Growth and development are also influenced by factors such as the nature of regulatory standards and economic incentives for reducing environmental degradation, availability and affordability of technologies, and availability of complementary knowledge and skills, as well as broader issues of institutional capacity and governance (Toman et al., 2011).

Large infrastructure investments in Africa have catalysed growth, helping many African countries catch up to middle income countries in terms of development (World Bank, 2012*a*). However, many countries still have a serious shortage of key infrastructure services and the existing ones are often of poor quality or under-maintained. To improve access and quality of infrastructure services and to meet fast-growing future demand, a substantial amount

FIGURE 5.1

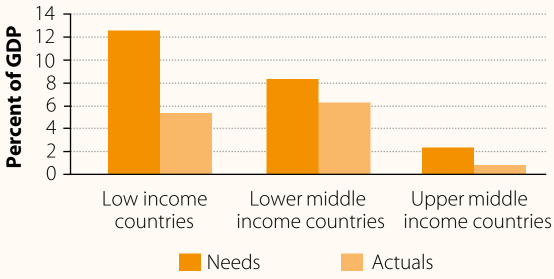
Infrastructure investment and economic development



Source: World Bank (2012a, fig. 4, p. 6). © World Bank, Washington, DC.

FIGURE 5.2

Needs versus actual investment in infrastructure



Source: Qureshi (2011, and source cited therein). © World Bank, Washington, DC.

of investment and operation and maintenance (O&M) spending is required. Infrastructure gaps exist in the majority of countries, however, the gap is especially large in low income countries (Figure 5.2).

Estimates suggest that developing countries will require US$1.1 trillion in annual expenditure through 2015 to meet growing demand for infrastructure (World Bank, 2011). This is more than double their $500 billion annual spending (Qureshi, 2011). These estimates are even higher if climate change mitigation and adaptation strategies are incorporated. Funding gaps threaten economic growth and could lead to an increase in the number of people living in poverty. Regarding energy infrastructure, the IEA has estimated that nearly $1 trillion in cumulative investment ($49 billion per year) will be needed to achieve universal energy access by 2030 (IEA, 2012*a*). It also concludes that in a business-as-usual scenario, one billion people will remain without access to electricity by 2030. Investment requirements for water infrastructure are even higher. For developing countries alone, it has been estimated that $103 billion per year are required to finance water, sanitation and wastewater treatment through 2015 (Yepes, 2008). Middle income countries such as Brazil, China and India are all already committing considerable resources to develop their infrastructure.

Traditionally, most infrastructure services have been provided by the public sector. It is estimated that 75% of water infrastructure investments in developing countries comes from public sources (Rodriguez et al., 2012). Nevertheless, given the infrastructure financing gap, the public sector alone cannot provide enough funding to satisfy the needs of the increasing demand for services. Private capital must be involved to close the gap. Private investors are, however, usually reluctant to invest in infrastructure projects, including those relating to water and energy, due to the risks involved such as a long pay-off period, lumpy investments and the sunk nature of the investment. When they do invest, they prefer to work in middle income countries where the risk is lower and capacities are high, leaving low income countries dependent on volatile public budgets and donor commitments. There is a need for an environment that enables private investment in infrastructure in tandem with the public sector to promote sustainable service delivery, especially in the poorest countries. Such an environment includes, among other features, coordinating efforts by the private sector, governments and international institutions; enhancing capacity-building of local institutions; improving public spending and its monitoring; and reducing investment inefficiencies and helping utilities to move towards cost recovery.

Funding gaps threaten economic growth *and could lead to an increase in the number of people living in poverty. Regarding energy infrastructure, the IEA has estimated that nearly $1 trillion in cumulative investment ($49 billion per year) will be needed to achieve universal energy access by 2030. It also concludes that in a business-as-usual scenario, one billion people will remain without access to electricity by 2030.*

Tools governments can use to attract and leverage private financing include public expenditure reviews and results-based financing (Rodriguez et al., 2012). International organizations have an important role in fostering mutually beneficial public–private partnerships, enabling the implementation of sound governance frameworks, and promoting sustainable and integrated planning so that future infrastructure is lower in maintenance, less expensive and more efficient. Given the limited resources and the size of the financing gap (which, although significant for energy, is far greater for water), it is crucial to ensure that investments are as efficient and as cost-effective as possible. Spending efficiency is a chronic problem in many developing countries. Recent work by the IEA (2010) suggests that in 2008, energy consumption subsidies added up to more than US$550 billion globally, but much of it was not properly targeted and provided limited benefits to the poor (Toman et al., 2011). It is important to explore innovative approaches to spending efficiency, such as cross-sector cooperation to leverage possible synergies, integrated planning for water and energy to decrease costs and ensure sustainability, trade-off assessment at the national level, demand-side interventions and decentralized services.

Investment requirements for water infrastructure are even higher [than for energy infrastructure]. For developing countries alone, it has been estimated that $103 billion per year are required to finance water, sanitation and wastewater treatment through 2015.

5.2 Opportunities for synergies in water and energy infrastructure

An array of opportunities exists to co-produce energy and water services and to exploit the benefits of synergies. However, the current political and economic incentive system still favours independent sectoral outcomes over cross-sectoral results. Sustainable solutions require a systems approach of integrated solutions rather than addressing issues in isolation. Water and energy issues should be addressed holistically, as the optimal solution for one can have negative impacts on the other. Such common solutions can be achieved only if there is communication between sectors, and if the right incentives are in place. In addition to new technical solutions, new political and economic frameworks need to be designed to promote cooperation among sectors and integrated planning.

For example, given the different uses of dams, hydropower sustainability can be improved through integrated water and energy planning and management. Most thermal power plants require large amounts of water to dissipate the excess produced heat ('waste heat') to the environment (Section 3.3.1). Therefore, the siting of power plants should take into account their interaction with water resources, water facilities and other sectors that compete for water supplies. There are also ways to utilize waste heat and thus decrease the amount of water needed for cooling, as explained in examples below. Wastewater treatment plants can generate energy from sludge produced at the plant. Another opportunity to mitigate nexus trade-offs is to improve water and energy efficiency and conservation. Improving efficiency in the water domain saves energy for treatment and supply and therefore reduces the amount of water needed by the power sector. When the power sector shifts towards a more efficient operation, less water is used as less waste heat will have to be dissipated. Thus, policies and integrated plans that encourage energy and water conservation can reduce future energy and water requirements.

5.2.1 Combined power and desalination plants

Combined power and desalination plants (also known as hybrid desalination plants) are an example of integrated infrastructure to produce drinking water and electricity. This solution is especially suited to extreme arid areas such as the Middle East, where there is very little water available and where desalination is likely to expand (Chapter 12). Examples of hybrid desalination plants are the Fujairah plant in the United Arab Emirates and the Shoaiba plant in Saudi Arabia.

Desalination is a more energy intensive process than traditional water treatments (Section 2.3). Despite this, desalination might be necessary in some regions of the world to meet the growing demand for industrial and domestic water supplies. Hybrid desalination plants use an innovative process to integrate desalination with thermal power generation, which improves efficiency and lowers the electricity cost of desalination processes. Waste heat from the power plant (steam) is used as the heat source for the desalination process.

Integrated water and energy production has several benefits. First, waste heat becomes a useful part of the process, decreasing the volume of water required for cooling purposes in the plant. Second, the cost of desalinating water decreases, making it more economically attractive, and the integrated system is more efficient than the stand-alone option (a separate power plant and a separate desalination plant) (Pechtl et al., 2003). However, there are also disadvantages. The integrated system is more complex to operate, mainly due to seasonal variability. During winter, demand for electricity can decrease (in warmer climates) while demand for water can remain relatively constant all year long. Demand variability can be managed, but when the two demands are not aligned, the system runs below maximum efficiency.

5.2.2 Alternative water sources for thermal power plant cooling

Thermal power plants require water mainly for cooling. The quality of this water does not need to meet drinking water standards, so there is a potential to explore alternative non-freshwater sources that could be used for the purpose. Although using alternative water sources can be challenging (e.g. cost will vary depending on location of the source and quality of the water), this option has a great potential to reduce freshwater use. One widely used alternative source is seawater, but this option only works if the power plant is located on the coast. Another option, relevant to the integration of water and energy infrastructure, is the use of wastewater for cooling.

Wastewater usually contains many polluting substances such as soaps, organic matter, oils and chemicals. The treatments necessary to meet the water quality standard to avoid corrosion and other undesired effects in the cooling system can be expensive and sometimes complex. In some countries, power plant operators need to obtain permits to use reclaimed water for cooling, which can be a burden. However, in those same countries, wastewater treatment plants are often required to pre-treat municipal water before discharging it back to the source, usually to at least secondary treatment standards. This makes wastewater an attractive option for cooling. Although additional treatments might be required before running the wastewater through the cooling system (e.g. sand filtration, coagulation and chlorination), these processes are widely used in water treatment plants around the world (Veil, 2007).

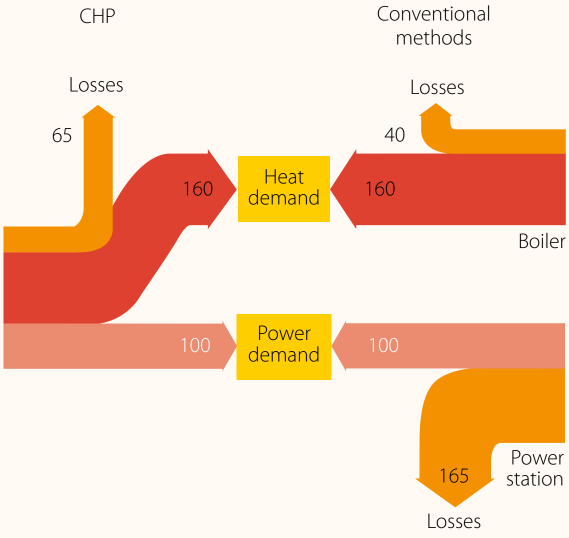
One important advantage of wastewater for cooling is that it is a source available all around the world, particularly in large cities. Securing wastewater from a nearby wastewater treatment plant could reduce future uncertainty and ensure a reliable, continuous water source for the power plant. Even if initial capital investment is high, it can make economic sense in the long term. This integrated solution is already being used in some countries. In the USA, wastewater is used for cooling in 50 power plants including Palo Verde in Arizona, the largest nuclear power plant in the country. Water is a scarce and valuable resource in Arizona and the power plant uses wastewater from several large cities as its only cooling source. The wastewater is piped in and re-treated on-site before use. Once run through the cooling system, the wastewater is transported to a pond where it evaporates. The power plant has recently secured 98.4 million m^3 wastewater per year until 2050 (Averyt et al., 2011). An important barrier to implementing this solution worldwide is that many developing countries lack sanitation infrastructure. However, this option presents a great opportunity to plan integrated water and energy infrastructure in the future and avoid the lock-in inefficiencies of developed countries.

5.2.3 Combined heat and power plants

Combined heat and power (CHP) plants (also known as cogeneration plants) integrate power and usable heat production into a single process. Whereas in conventional power plants half or more of the produced heat (on average) gets lost as waste heat (dissipated into the environment through the cooling system), in CHP plants the heat is usually used for district heating as steam or hot water. CHP plants can be implemented with most fuel sources (natural gas, coal, solar thermal), allowing them to be adapted to any environment, though different plants will achieve different efficiencies.

An important advantage of CHP plants is that an integrated power and heat generation process tends to be more efficient than the two stand-alone processes (Figure 5.3), thus decreasing GHG emissions and diminishing water requirements. The combined efficiency of the heat and power processes (total energy output by energy input) can reach as high as 90% (IEA, 2008*a*). CHP plants rely on existing and well-known technologies and are used in many parts of the world. In Denmark about 50% of the total power generated is produced in CHP plants (IEA, 2008*a*). Another recent example is the city of Boston, where the Kendall power plant, which already sends heat to the Massachusetts General Hospital, will send additional heat to Boston to avoid regulatory problems due to water intake and discharges (Daley, 2011).

FIGURE 5.3 **Sankey diagram of combined heat and power (CHP) and conventional power plants**



Source: 'What is CHP?' page of CHP Focus website, DEFRA, now on The National Archives. © Crown copyright 2008.

CHP plants are more efficient when located near the source of demand for heat and power (i.e. a city, a village, an industrial complex). If heat has to be transported far from its production site, a significant percentage gets lost and process efficiency drops considerably. CHP plants are thus well suited as decentralized forms of energy supply.

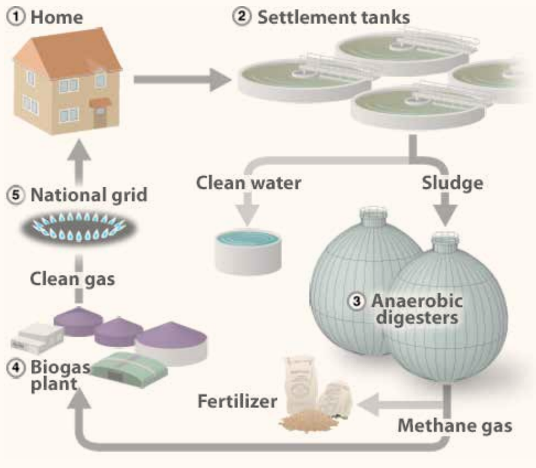
On the other hand, CHP plants require higher initial capital investment than a conventional power plant. The payback time is usually quite long, although they are more economical in the long term due to the energy savings. As with combined desalination and power plants, another disadvantage of CHP plants is the seasonal variation that affects their performance. Meeting two demands (heat and power) adds an extra layer of complexity to plant operations. During summer, it can become challenging to deal with the extra heat.

5.2.4 Sewage water energy recovery

In many cities around the world and especially in developing countries, faecal sludge management is one of the most significant health problems. Anaerobic digestion is an option that could be implemented in many wastewater treatment plants to (a) reduce sludge volume and disposal costs; (b) produce a source of green energy (biogas); (c) use organic material as a fertilizer; and (d) eliminate pathogens (see Chapters 17 and 24 [Volume 2] for the case studies 'Green energy generation in Vienna, Austria' and 'Green energy production from municipal sewage sludge in Japan', respectively).

5.4 FIGURE

Biogas production in a wastewater treatment plant



Note: For more detail on the numbered stages, see http://news.bbc.co.uk/2/hi/uk_news/magazine/8501236.stm (Accessed Oct 2013)
Source: Shah (2010). © BBC News.

The biogas produced in wastewater treatment plants (Figure 5.4) comprises primarily methane (CH_4) and carbon dioxide (CO_2) and is produced by anaerobic digestion or fermentation of biodegradable materials such as sewage, manure, human municipal solid waste and green waste. Biogas can be sold as gas for heat and cooking, as vehicle fuel or as fuel for a power plant, or can be burnt on-site to produce electricity and heat for the treatment plant (Box 16.3). The remaining sludge can be sold as fertilizer for agriculture purposes, which makes this practice economically viable in the long term depending on the price of gas and fertilizer. There are several environmental benefits: biogas can replace fossil fuels (e.g. natural gas, coal for cooking), thereby reducing GHG emissions; and given the reduction in sludge volume after digestion, landfill lifespan can be extended.

There are several examples of this integrated water and energy solution throughout the world. The size of wastewater treatment plants with anaerobic digesters varies considerably, with important economies of scale in terms of both cost and energy consumption. La Farfana wastewater treatment plant treats urban water from 50% of the population of Santiago, Chile (population equivalent of 3.7 million people), and produces around 24 million m^3 per year in biogas (Degrémont, n.d.). This biogas is sold to the gas utility company (Metrogas) and directly replaces natural gas being used in households, benefiting around 100,000 people in the metropolitan area (Aguas Andinas, n.d.). There are also examples of smaller scale decentralized biodigester projects; for example, in India (Müller, 2007), where the biogas is used for cooking.

Biogas generated can also be burnt on-site in a CHP plant to generate both heat and electricity in a highly efficient process (discussed earlier). The heat produced by the CHP plant is used in the digester to dry the sludge and for space heating the plant facilities, and the power is used in the plant or sold to the grid. All or most of the plant power needs can be met by electricity generated at the plant, and thermal requirements of the biodigesters can be met by heat generated at the plant, which reduces costs by displacing fuel purchasing. Depending on local electricity prices, the CHP plant can produce electricity below retail cost, which can create a compelling case for private investors. Having its own decentralized power source also enhances plant reliability, which is important in areas that experience frequent power outages. Biogas is a 'green' energy source and therefore generating power and heat from burning it can potentially reduce GHG emissions and other air pollutants (if it replaces fossil fuels). Due to its benefits, implementation of CHP plants at wastewater treatment plants is growing in popularity as a way to reduce environmental impacts and increase efficiency. In the USA, there are 104 wastewater treatment plants using biogas to produce a total of 190 MW capacity (US EPA, 2011).

5.3 Moving forward

The complex interlinkages between water and energy systems requires a more systematic approach that takes into account the multiple interactions and relationships between domains, and explores strategic complementarities and potential synergies across all sectors. Energy and water planning must be better integrated to optimize investments and avoid inefficiencies. Similarly, cross-sectoral implications need to be better understood. In addition to taking water constraints in the energy sector into account when undertaking power expansion plans, there are many opportunities for joint development and management of water and energy infrastructure and technologies, maximizing co-benefits and minimizing negative trade-offs. When assessing the needs of the energy sector, water planners and decision-makers must fully understand the requirements of electricity generation and fuel extraction technologies and their potential impact on the resource. Similarly, energy planners and investors must take into account the complexities of the hydrological cycle and other competing uses when assessing plans and investments. One way of ensuring robust planning efforts is by implementing technical approaches and reforming governing institutions. Technical approaches may include (but are not limited to) the ones described in this chapter. Institutional reform requires integrated planning and cross-sectoral communication to bolster efforts to mitigate inefficiencies in the energy–water nexus, and must be achieved before technical solutions can be successfully adapted. An integrated energy and water planning approach can ensure that both resources are developed sustainably, and that synergies are explored more effectively. Meeting future demands requires innovative approaches that encourage cross-sectoral cooperation and help to better assess water and energy trade-offs at the national and regional levels.

> ***When assessing the needs of the energy sector,*** *water planners and decision-makers must fully understand the requirements of electricity generation and fuel extraction technologies and their potential impact on the resource. Similarly, energy planners and investors must take into account the complexities of the hydrological cycle and other competing uses when assessing plans and investments.*

CHAPTER 6

Food and agriculture

FAO

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6.1 The water–energy–food nexus

Water, energy and food are inextricably linked. Water is an input for producing agricultural goods in the fields and along the entire agrifood supply chain. Energy is required to produce and distribute water and food: to pump water from groundwater or surface water sources, to power tractors and irrigation machinery, and to process and transport agricultural goods. Agriculture is currently the largest user of water at the global level, accounting for 70% of total withdrawal. The food production and supply chain accounts for about 30% of total global energy consumption (FAO, 2011*b*).

There are many synergies and trade-offs between water and energy use and food production. Using water to irrigate crops might promote food production but it can also reduce river flows and hydropower potential. Growing bioenergy crops under irrigated agriculture can increase overall water withdrawals and jeopardize food security. Converting surface irrigation into high efficiency pressurized irrigation may save water but may also result in higher energy use. Recognizing these synergies and balancing these trade-offs is central to jointly ensuring water, energy and food security. This chapter considers the implications of water and energy for food security by focusing on irrigation, hydropower and biofuels.

6.2 The effects of increasing food demand on water and energy

An estimated 870 million people are undernourished due to a lack of food or a lack of access to food (FAO, 2013*a*). Demographic projections suggest that world population will increase by a third – to 9.3 billion – by 2050 (UNDESA, 2012). Most of this increase will occur in developing countries, where population growth will be coupled with rising incomes, urbanization and climate change to place considerable pressure on national and global food systems. Estimates suggest that global food production will need to increase by as much as 60% by 2050 to meet demand (FAO, 2012). Achieving such a dramatic increase is a formidable challenge.

Agriculture currently uses 11% of the world's land surface, and irrigated agriculture uses 70% of all water withdrawals on a global scale. Rainfed agriculture is the predominant agricultural production system around the world, and its current productivity is, on average, little more than half the potential obtainable under optimal agricultural management. Water scarcity and decreasing availability of water for agriculture constrain irrigated production overall, and particularly in the most hydrologically stressed areas and countries. As many key food production systems depend on groundwater, declining aquifer levels and the depletion of non-renewable groundwater put local and global food production at risk (Section 2.4). Increasing food production is not, on its own, sufficient to achieve food security and eradicate hunger. Hunger can persist in the midst of adequate national and global food supplies. Efforts to promote food production must be complemented by policies that enhance household access to food, either by creating employment and income opportunities or by establishing effective safety net programmes. The experiences of countries like Brazil and China, which have undergone strong economic growth and succeeded in significantly reducing hunger and malnutrition, show that economic growth alone does not automatically ensure food security – the source of the growth matters too, along with the distribution of the economic gains and social benefits. Growth originating in agriculture, in particular in the smallholder sector, is at least twice as effective as growth in non-agricultural sectors in benefiting the poorest members of society in rural areas (FAO, 2009*a*).

Access to modern energy services is extremely problematic for households in many developing countries, particularly in rural areas. The IEA estimates that one-fifth of the world's population lacks access to electricity and that two-fifths rely on traditional biomass for cooking – a cause of severe indoor air pollution, which affects women in particular (Table 1.1). Rural electrification can address these issues and boost rural economies, in turn increasing household food security. It also frees up time spent by household members – mostly women and girls – in collecting the biomass. To meet rising household energy demands, an especially difficult challenge in rural areas, new energy sources must be found that are technically, economically and environmentally viable (Box 6.1).

6.3 Water for energy and the linkages to food security

Hydroelectricity generation is one way to help meet future energy demands. Multi-purpose dams can provide energy as well as water for irrigation and flood management. However, water demand for energy production can be in conflict with water demand for agriculture. In Central Asia, dams in the mountains of Kyrgyzstan and Tajikistan once collected water in autumn and winter that was released in spring and summer to irrigate cotton and wheat in Uzbekistan, Turkmenistan and Kazakhstan. Upstream countries were compensated for this water by cheap oil and gas from downstream countries. However, rising energy prices made it beneficial for upstream countries to generate more hydropower in winter by releasing water that could not then be used for irrigation. As a result, downstream countries, maintaining the same crop and production patterns, had insufficient water in summer to satisfy agricultural demand. Dam and reservoir management procedures, cropping patterns, irrigation practices and compensation packages that are agreeable to all countries involved have not yet been achieved (FAO, 2013*b*). There are concerns that this situation may prompt nations like Uzbekistan to start considering alternative water sources for irrigation, such as groundwater (Karimova et al., 2010).

> ***As groundwater irrigation,*** *in general, provides greater flexibility than other types in responding to fluctuating water demands, its relative importance is likely to increase in the future*

The benefits of hydropower generation do not always flow to the people who depend on rivers for their livelihoods (WCD, 2000). The creation of reservoirs has displaced millions of people throughout the world. Damming rivers to produce energy can have adverse impacts on important

6.1 BOX

Renewable energy technologies for improved irrigation efficiency help women farmers

Renewable energy technologies are already helping communities, women and men, to meet water, fuel and food security needs in clean and cost-efficient ways. In Mozambique, the UN Joint Programme on Environmental Mainstreaming and Adaption to Climate Change (FAO, UNDP, UNEP, UN-Habitat, UNIDO, WFP) supported the installation of renewable energy systems for water, irrigation and electricity in seven different communities, and built the capacities of community members to maintain the systems. By providing marginalized communities with renewable energies and clean, accessible drinking water, women's lives were transformed by lessening the burden of fetching unsafe water and increasing opportunities for income generation and other pursuits. Due to the project's very positive impact, the Government of Mozambique and the National Energy Fund (FUNAE) have replicated its best practices and have rolled out the initiative in other rural communities (see http://mdgfund.org for more information). Another example is the Solar Electric Light Fund's (SELF) Solar Market Gardens in Benin that use solar-powered drip irrigation systems to help women farmers in remote, arid regions grow crops during the dry season. With drip irrigation – a proven efficient and labour-saving technology that delivers water directly to plant roots and facilitates simple and uniform fertilizer application – farmers can achieve higher yields over larger areas with less water and labour. The initiative reduces greenhouse emissions while allowing women farmers to increase their income and improve food security for their families (see http://self.org for more information).

Source: UN Women.

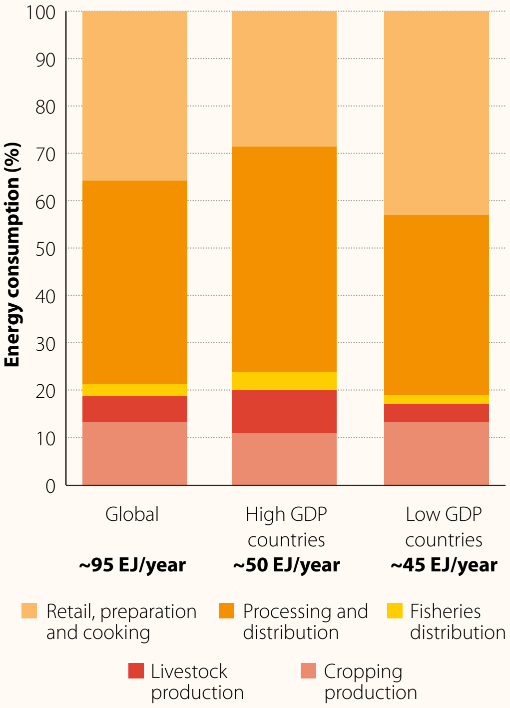
inland fisheries by changing water flow rates and timing, fragmenting habitat and disrupting fish migration routes (Section 9.2). These issues are becoming more apparent in many river basins; the Lower Mekong is a notable example. Changing a riparian environment to a reservoir changes the community of fish in the water body. Although the fish in reservoirs can be harvested and reservoir fisheries developed, compensation for the loss in yield from river fisheries can be difficult to achieve (Marmulla, 2001). However, reservoirs can have advantages over rivers as aquaculture facilities. Fish farming in floating cages in lakes and reservoirs is an effective way to use hydroelectric dams for the direct production of food. Cage farming can help compensate farmers and fishers for losses after the building of dams.

6.4 Energy use in agrifood systems

Estimates are that the food sector[15] currently accounts for about 30% of the world's total end-use energy consumption, and that more than 70% of that energy is used beyond the farm gate (FAO, 2011*b*). Figure 6.1 illustrates the percentage beyond production for processing, distribution, retail, preparation and cooking in countries grouped by Gross Domestic Product (GDP). Developed countries use a greater portion of this energy for processing and transport; in developing countries, cooking consumes the highest share.[16]

FIGURE 6.1

Indicative shares of final energy consumption for the food sector globally and for high and low Gross Domestic Product (GDP) countries



Source: FAO (2011b, fig. 6, p. 11, based on sources cited therein).

On an annual basis, the direct energy demand of primary production is about 2,200 TWh, which equates to less than 2% of total end-use energy consumption (FAO, 2011*b*). On-farm direct energy demand is about 1,700 TWh, and is used mainly for pumping irrigation water, housing livestock, and cultivating, harvesting, drying and storing crops (OECD, 2008, ch. 1, section 1.4, 'Energy'). Indirect energy demands for operating tractors and other farm machinery as well as for fertilizer manufacturing is about 2,500 TWh (UK GOS, 2011). The synthesis of nitrogenous fertilizers alone consumes approximately 1,400 TWh. Global primary production in fisheries directly consumes about 550 TWh of total final energy annually, mainly for boat propulsion, pond aeration and water pumping (Muir, 2010; FAO, 2009*b*). Indirect energy embedded in aquaculture feedstuffs is about 140 TWh (Smil, 2008). These figures illustrate how heavily dependent agriculture is on the energy sector.

Powering the pumps on a total of 300 million irrigated hectares consumes around 62 TWh/year. Manufacture and delivery of irrigation equipment consumes another 62 TWh (Smil, 2008). The 112 million ha or so globally that are irrigated by groundwater account for most of the energy used for irrigation. As groundwater irrigation, in general, provides greater flexibility than other types in responding to fluctuating water demands, its relative importance is likely to increase in the future.

Groundwater for irrigation can be withdrawn from both shallow and deep aquifers. Where extraction rates from shallow groundwater stores exceed recharge rates, water abstracted from greater depths, pumped by energy intensive electric pumps, will likely become more important. Avoiding groundwater depletion, through sustainable groundwater management, can lead to long-term cost and energy savings (Section 2.3).

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[15] In this context, 'food sector' concerns those parts of 'agriculture' in the broad FAO sense; that is, agriculture, forestry and fisheries that produce food as well as the food processing, distribution, retail, preparation and cooking phases.

[16] For a comprehensive examination of water use, see WWAP (2012, chs 2, 'Water demand: What drives consumption' and 18, 'Managing water along the livestock value chain').

6.5 Biofuels, water and food security linkages

Biomass can be used to produce a range of fuels that can be used for heating, power generation and transport (Section 3.2.2). Biofuels have, in certain contexts, the potential to provide a cleaner alternative energy source to fossil fuels. Many developing countries have considerable prospects to raise agricultural productivity, and biofuels could help achieve broader rural development. Bioenergy investments can be arranged so that they not only generate profits for investors, but also involve smallholders, thereby creating jobs, improving livelihoods and reducing poverty in rural areas. Feedstock production through a combination of large-scale plantation farming and smallholder outgrower schemes is an example of such an arrangement. Smallholder outgrower schemes used to produce biofuel crops can also benefit other crops if they deliver modern seed material and agro-chemical inputs, improve farming practices and provide marketing support.

Optimism over biofuels is tempered by concerns over their economic viability and their implications for socio-economic development, food security and environmental sustainability (Section 9.2.2). Although bioenergy investment can improve income, employment and market access, it can have negative consequences for traditional land tenure arrangements. This is particularly the case

TABLE 6.1 **Indicative yields and water requirements for some major biofuel crops**

Crop	**Fuel product**	**Annual obtainable yield (L/ha)**	**Energy yield (GJ/ha)**	**Potential crop evapo-transpiration (in mm, indicative)**	**Evapo-transpiration (L/L fuel)**	**Irrigated or rainfed production**	**Rainfed conditions**	**Water resource implications under irrigated conditions (assuming an irrigation efficiency of 50%)**	
							Actual rainfed crop evapotranspiration (in mm, indicative)	**Irrigation water used (in mm, indicative)**	**Irrigation water used (in L/L fuel, indicative)**
Sugar-cane	Ethanol (from sugar)	6 000	120	1 400	2 000	Irrigated/ rainfed	1 100	600	1 000
Sugar beet	Ethanol (from sugar)	7 000	140	650	786	Irrigated/ rainfed	450	400	571
Cassava	Ethanol (from starch)	4 000	80	1 000	2 250	Rainfed	900	–	–
Maize	Ethanol (from starch)	3 500	70	550	1 360	Irrigated/ rainfed	400	300	857
Winter wheat	Ethanol (from starch)	2 000	40	300	1 500	Rainfed	300	–	–
Palm oil	Bio-diesel	6 000	193	1 500	2 360	Rainfed	1 300	–	–
Rapeseed/ mustard	Bio-diesel	1 200	42	500	3 330	Rainfed	400	–	–
Soybean	Bio-diesel	450	14	500	10 000	Rainfed	400	–	–

Note: 1 GJ/h = 277.8 kW.
Source: Hoogeveen et al. (2009, table II, p. S153, adapted from source cited therein).

for marginal land, which provides important ecosystem services such as pasture land or fuel wood for local traditional communities (Cotula et al., 2008). Marginal land is also a target for rehabilitation for food production or sequestering carbon (e.g. forest regrowth).

Biofuels have been heavily debated due to concerns over trade-offs with food security. The debate has largely focused on first generation biofuels: ethanol and biodiesel produced from feedstock such as maize, sugarcane and palm oil.[17] The contribution of biofuels to the recent food price increases is difficult to disentangle from other factors such as rising food demand in emerging economies, declining food stocks, fluctuating oil and natural gas prices, commodity speculation, and a succession of low harvests in major food producing regions. Nonetheless, the demand for agricultural feedstock for biofuels is the largest source of new demand for agricultural production in decades, and it was a major factor behind the 2007–2008 spike in world commodity prices. For example, FAO (2011*c*) estimates that biofuels accounted for about one-third of the maize price increase. This raises concerns about the implications that global biofuel production may have on food security in developing countries.

When considering feedstock production for biofuels, the most important distinguishing characteristic of a biofuel from a water systems perspective is whether it is produced from rainfed or irrigated feedstock crops. In general, rainfed production does not substantially alter the water cycle, whereas irrigated production extracts groundwater or uses surface water and can have important implications for local water availability. When assessing the impact of biofuel production on water and food security, land is the key factor for rainfed agriculture, while water is the key factor for irrigated agriculture. Water used in biofuel processing is a strong competitor for local uses, but it can be returned to rivers and other water bodies and made available for further use. However, these return flows often have negative impacts due to chemical and thermal pollution.

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[17] Other first generation feedstocks include sunflower and other oilseeds, cassava, and wheat and other grains.

6.2 TABLE

Water consumed through evapotranspiration per unit bioenergy feedstock production and per unit gross bioenergy production

Biofuel	Feedstock	Energy crop evapotranspiration (ET)[a] (tonne water per GJ feedstock)		Total water use in the production chain (tonne water per GJ gross electricity or biofuel output)	
Traditional food crop		**Low case**	**High case**	**Low case**	**High case**
Biodiesel	Rapeseed	45	80	100	175
Ethanol	Sugarcane	25	125	35	155
	Sugar beet	55	150	70	190
	Corn	35	190	75	345
	Wheat	20	200	40	350
Lignocellulosic crop[b]		5	70		
Ethanol				10	170
Methanol				10	135
Hydrogen				10	125
Electricity				15	195

Note: 1 GJ = 277.8 kWh.

[a] Lower range numbers refer to systems where (a) harvest residues from non-lignocellulosic crops (50% total amount of residues) are used for power production at 45% efficiency or (b) higher efficiencies in processing lignocellulosic crops are achieved. When ethanol is produced from sugarcane or lignocellulosic feedstocks, process by-products (bagasse and lignin, respectively) are used for internal heat and electricity. Here, lower range numbers refer to system designs allowing for export of electricity in excess of internal requirements. [b] For example, short rotation woody crops such as willow and eucalyptus and grasses such as miscanthus and switchgrass.

Source: Adapted from Berndes (2002, table 2, p. 259, based on sources cited therein).

If bioenergy feedstock is produced on irrigated lands, then the potential impact of biofuels on water resources is also of major concern. This is most relevant for commercial feedstock production. Biofuels use water for both feedstock production and processing stages. Consequently, the water requirements of biofuels produced from irrigated crops can be much larger than for fossil fuel resources (Figure 3.1), although fossil fuels can have much larger environmental impacts. Table 6.1 presents the variability of yields across crop types and provides indicative water requirement levels of rainfed and irrigated crops. Table 6.2 illustrates water requirements along the entire biofuel production chain. Although the water footprint of second generation biofuels (e.g. from non-edible crops, crop residue and algae) could be much lower, production remains almost entirely at the pilot-project level.

Overall, biofuel development needs to be considered in the context of food security, energy needs, land availability, and other national priorities. Biofuels are neither good nor bad and are subject to the same constraints and challenges as the rest of the agricultural sector. What is essential is that the biofuel options be viewed as an agriculture investment option that needs to be sustainable and smallholder inclusive in order to target poverty reduction and rural development and to safeguard food security.

__For both large and small systems__, any means of avoiding food wastage should be encouraged and can result in considerable savings in the energy, land and water used to produce this food that no one consumes

6.6 Energy-smart agriculture

Energy efficiency measures can be applied at all stages along the agrifood chain. Table 6.3 presents examples of energy efficient farming practices. Energy efficiency improvements can bring direct savings through technological or behavioural changes, or indirect savings through co-benefits derived from the adoption of agro-ecological farming practices. For both large and small systems, any means of avoiding food wastage should be encouraged and can result in considerable savings in the energy, land and water used to produce this food that no one consumes.

Knowledge-based precision irrigation, which provides reliable and flexible water application, along with deficit irrigation and wastewater reuse, will be a major platform for sustainable crop production intensification (FAO,

TABLE 6.3

Examples of energy efficiency improvements at the farm level

Direct intervention	Indirect intervention
Adoption and maintenance of fuel efficient engines	Improved water allocation and management of water demand
Precise water application	Improved surface water delivery to reduce the need for pumping
Precision farming for fertilizers	Provision of water services for multiple water use
Adoption of no-till practices	Reduced water losses
Energy efficient buildings	Crop varieties and animal breeds that demand less input (including multipurpose crops and perennials)
Heat management of greenhouses	Reduced soil erosion
Propeller design of fishing vessels	Use of bio-fertilizer
Use of high efficiency pumps (high cost)	Efficient machinery manufacture
	Identification of stock locations and markets by information and communications technology

Source: Adapted from FAO (2011b, table 5, p. 20).

2011*d*). Mechanical irrigation systems should be designed to use water as efficiently as possible. Crops often take up only half of the irrigation water applied (FAO, 2011*d*), so there is clearly potential to improve water use efficiency, which would also result in less demand for electricity or diesel fuel for pumping. However, much controversy and debate exist about the engineering concept of 'water use efficiency' (FAO, 2012). It is widely accepted that, while irrigation losses appear high, a large part of these 'losses' return to the river basin in the form of return flow or aquifer recharge, although the water quality of the return flows may have been altered. Measures to increase water use efficiencies upstream, while maintaining existing levels of withdrawal, will increase the productive efficiency of water use, but at the same time, may deprive downstream users who depend on return flow in rivers or groundwater aquifers fed from these returns. Still, from the energy point of view, it remains worthwhile to increase water use efficiencies to prevent energy being spent in pumping the same water twice (upstream and again downstream).

Dam and reservoir design that accommodates fisheries and aquaculture will allow continued food production from rivers that are dammed for hydroelectric development. To protect increasingly scarce water resources for food and energy production, in terms of both quantity and quality, increased attention is required for water management in upstream and mountain areas. Watershed management is an appropriate approach that comprehensively considers management of all available natural resources, and links this management to agricultural production and livelihoods (Section 9.3.5). Through proper watershed management, the risk of some natural hazards (such as landslides and localized floods) can be reduced, surface water flows regulated, sediment loads in river systems reduced and water quality maintained – all indispensable characteristics for successful and sustainable food and hydropower production. Optimizing the management of storage capacity of reservoirs and catchments, including soils and groundwater, offers opportunities for improved efficiencies; for example, drawing upon groundwater reserves at times of low reservoir capacity and enabling groundwater to recharge when reservoirs are full.

***Market trends,** technological innovations and the availability of cheap (but not necessarily energy efficient) equipment can increase the use of energy in agriculture*

Market trends, technological innovations and the availability of cheap (but not necessarily energy efficient) equipment can increase the use of energy in agriculture. For example, public policy changes to subsidize fossil fuels have stimulated the import of innovative, cheap Chinese-made farm machinery to Bangladesh, which has led to the country's 'agro-tractorization'. Small, mobile diesel engines that are demountable and can be used for a range of applications, including powering pumps for irrigation, have increased food production and economic returns to farmers (Steele, 2011). The diesel engines can be repaired easily by local mechanics and are less expensive than more sophisticated and more fuel efficient machinery manufactured in India. Seeing these results, Nepalese and Indian farm machinery manufacturers have recognized a new business opportunity. Small engines are now being sold mainly in low-cost farm machinery markets in rural communities. Farm services have expanded as a result of the versatility and transportability of this equipment (Biggs and Justice, 2011). This example illustrates how inexpensive fossil fuels, made available and affordable through government subsidies, have delivered benefits to smallholder farmers using inexpensive diesel-powered farm machinery.

Subsidizing energy, in the form of fossil fuels, has benefited smallholder farmers in Bangladesh without over-exploiting water resources; however, energy subsidies in the form of cheap electricity in the drier parts of India have had detrimental effects on groundwater levels (Section 1.4). It is estimated that in India one million new tube wells become operational every year. In some parts of India, these wells are drilled ever deeper over time to obtain a consistent groundwater yield. More energy is needed and the quality of the extracted water is often poor, with high levels of harmful chemicals such as arsenic. In Gujarat, one of the drier states in India, policies to ration farm power supply, and thus water supply, have been recommended to encourage farmers to use water more sparingly (IWMI, 2011).

Modernization of existing canal irrigation systems to improve services may encourage farmers to reduce groundwater use, as it is often more expensive than surface water supply of similar quality. Modernized surface water supply systems not only improve water productivity and water use efficiency, but can also improve people's livelihoods. They have high potential to serve multiple uses such as in crop production, domestic purposes, animal husbandry and small industries.

6.7 Towards a nexus approach

The global community is well aware of food, energy and water challenges, but has so far addressed them in isolation, within sectoral boundaries. At the country level, fragmented sectoral responsibilities, lack of coordination, and inconsistencies between laws and regulatory frameworks may lead to misaligned incentives. If water, energy and food security are to be simultaneously achieved, decision-makers, including those responsible for only a single sector, need to consider broader influences and cross-sectoral impacts. They must strive for innovative policies and integrated institutions. Water development and management programmes, if planned properly, can serve multiple functions, from contributing to energy and food production to helping communities adapt to climate change. A nexus approach to sectoral management, through enhanced dialogue, collaboration and coordination, is needed to ensure that co-benefits and trade-offs are considered and that appropriate safeguards are put in place.

Sustainable and successful policy options best suited for a particular country should take into account all aspects of water, energy and food and should be based on sound technical, environmental (ecosystems) and economic information. This information should address issues on the availability and suitability of natural resources as well as socio-economic costs and benefits. An integrated approach includes:

- An in-depth understanding of synergies and trade-offs in the use of natural resources, while taking into consideration the role of ecosystem services, for the energy and agricultural sector

- An enabling policy and institutional environment, with sound and flexible policies and effective instruments to implement these policies to enforce good practices

- Proper impact monitoring, evaluation, reporting and policy response mechanisms

CHAPTER 7

Cities

UN-Habitat

Bhushan Tuladhar, Vincent Kitio, Robert Goodwin and Andre Dzikus

7.1 Global urbanization trends

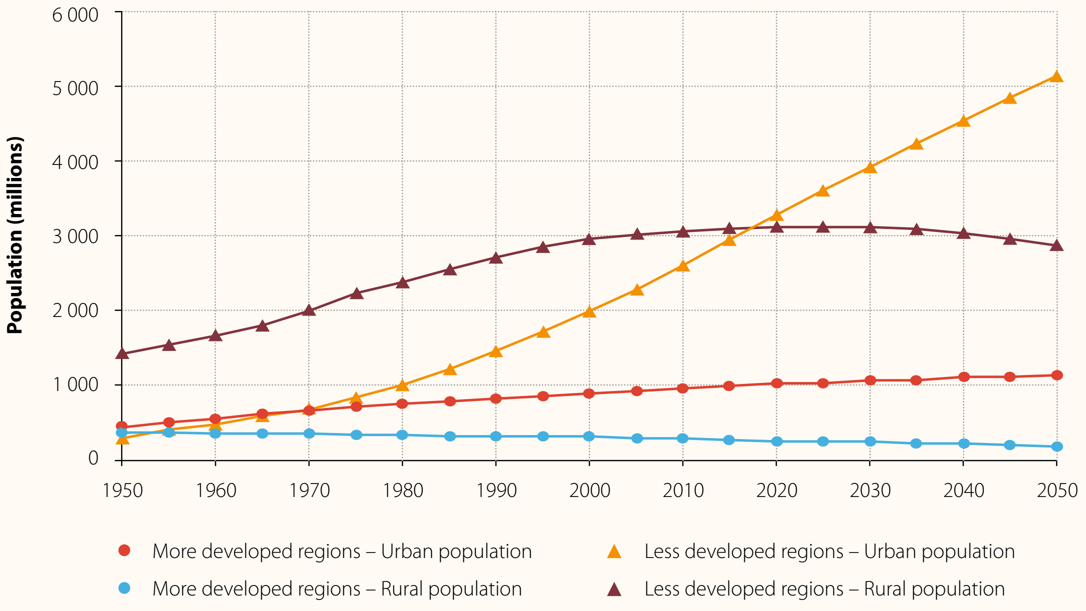
More than half of humanity currently lives in cities, and this proportion is expected to grow rapidly. Between 2011 and 2050, it is estimated that the world's population will increase by 2.3 billion, while the urban population will increase by 2.6 billion (UNDESA, 2012). This means that urban areas will absorb all the population growth over the next four decades while the rural population will start to decrease in about a decade. Almost all of this increase will be in cities located in developing countries, while the urban population in developed countries will remain close to constant (Figure 7.1). Between 2010 and 2015, almost 200,000 people are projected to be added to the world's cities every day; 91% of this growth is expected to take place in cities of developing countries (UN-Habitat, 2012).

In developing countries, urban growth will be concentrated in, but not limited to, larger cities. In 2011, about 60% of the world's urban population lived in cities with a population of less than one million people. By 2025, this will decrease to about 50%, while the number of people living in cities with more than one million will increase from 40% to 47%. The annual population increase in six major developing country cities – Dhaka, Karachi, Kinshasa, Lagos, Mumbai and New Delhi – is greater than the entire population of Europe (UN-Habitat, 2012).

As many of the rapidly growing cities in developing countries – particularly in Africa, South Asia and China – already face problems related to water and energy, and have limited capacity to overcome these problems, such cities will be major hotspots for water and energy crises in the future. Kathmandu, for example, is currently able to supply only about one-third of the total water demanded by its one million plus residents, who are also struggling with up to 14 hours per day of power cuts in the dry season. Yet the city continues to grow by about 4% per year (CBS, 2012). Cities like Kathmandu are illustrative of

FIGURE 7.1

Urban and rural populations by development group, 1950–2050



Source: UNDESA (2012, fig. 1, p. 3).

the challenge of providing adequate and sustainable water and energy services in the urban context.

7.2 Urban water and energy demands

Cities are complex systems that use inputs such as water, energy, food, materials and nutrients, much of which is imported from outside, and produce outputs such as waste, wastewater and emissions that pollute the surrounding environment. Growing urban populations and their increasing affluence generally lead to higher energy and water consumption for domestic use. In India for example, the government's norm for rural water supply schemes is 40 litres per capita per day (l.p.c.d.), but for towns without sewers it is 70 l.p.c.d., for cities with sewers it is 135 l.p.c.d., and for metropolitan and mega cities, with populations over 1 million, it is as high as 150 l.p.c.d. (CPHEEO, 1999). While these are design standards, the actual demand for water in these cities could be higher. Mumbai, for example, claims its water demand to be 300 l.p.c.d. (Narain, 2012). In the USA, which has a much higher per capita income than India, domestic indoor water use in cities averages 242 l.p.c.d. However, with the addition of outdoor irrigation, swimming pools and pipeline leakages the total per capita water usage in the USA reaches almost 650 l.p.c.d. (Novotny, 2012).

Although per capita water consumption generally increases with affluence, experience from some high income cities indicates that this relationship need not be linear, as some cities have started reducing their per capita water consumption after reaching a certain income level. This is mainly due to adoption of improved water conservation measures in homes, reduction in water losses (including leakage from urban distribution systems) and enhanced awareness among consumers. Per capita water consumption in New York City declined from 806 l.p.c.d. in 1980 to 481 l.p.c.d. in 2010 (NYC, 2012), a drop of more than 40%. Figure 7.2, comparing per capita income with per capita water consumption in selected Asian cities, also illustrates this phenomenon. Singapore's per capita GDP is more than twice that of neighbouring Kuala Lumpur, but its per capita water demand is much lower. The same is the case of Guangzhou and Hong Kong. This indicates that while there is bound to be rapid increase in water demand as cities continue to grow, there is also room to restrict the growth of per capita water demand or reduce it by using water conservation measures.

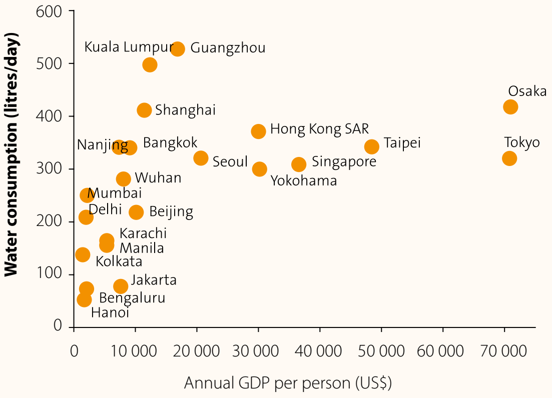
In addition to the water they directly consume, urban residents tend to have a large water footprint because of higher incomes, which is generally associated with a higher level of consumption of water intensive foods (Chapagain and Hoekstra, 2004) and economic structures that enable people in cities to have reliable supplies of water intensive goods. As this virtual demand of cities could exceed direct water use by an order of magnitude (Hoekstra and Chapagain, 2008), efforts can be made towards reducing this external water footprint.[18]

Cities not only consume large amounts of water, their high concentration of industry, transport systems and buildings also demands large amounts of energy. Cities are home to just over 50% of the global population, but they consume 60% to 80% of the commercial energy and emit about 75% of the GHGs (IEA, 2008*b*; UNEP, 2011*b*). As with water consumption, per capita energy consumption in cities depends on factors such as urban design, income levels, climate and consumption patterns of citizens. High density compact cities tend to have lower per capita energy consumption because less energy is required for transportation as well as for provision of services such as water supply and sanitation.

The difference between energy consumption in rural and urban areas also depends on the level of development. In industrialized countries, the per capita energy use of city residents is slightly lower than the national average,

FIGURE 7.2

Water consumption and per capita income in selected Asian cities



Note: Years differ from city to city from 2005 to 2009. Annual Gross Domestic Product (GDP) per person in US$ is based on current prices at the time.
Source: UNDP (2012, fig. 5.3, p. 125, based on source cited therein).

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[18] 'Water footprint' and 'virtual water' are defined in Section 8.3.

but in developing countries where the per capita energy consumption in rural areas is very low, urban residents have much higher per capita energy consumption. For example, the per capita energy use in urban China is almost twice as high as the national average due to higher average incomes and better access to modern energy services in the cities (IEA, 2008*b*). More than 90% of the future urbanization will happen in developing countries, resulting in a huge increase in global energy demand, which in turn will result in increasing water demand. The IEA (2012*a*) predicts that the water needs for energy production will grow at twice the rate of energy demand. The rapid growth of cities will therefore result in serious challenges associated with access to both water and energy in cities and their surrounding areas.

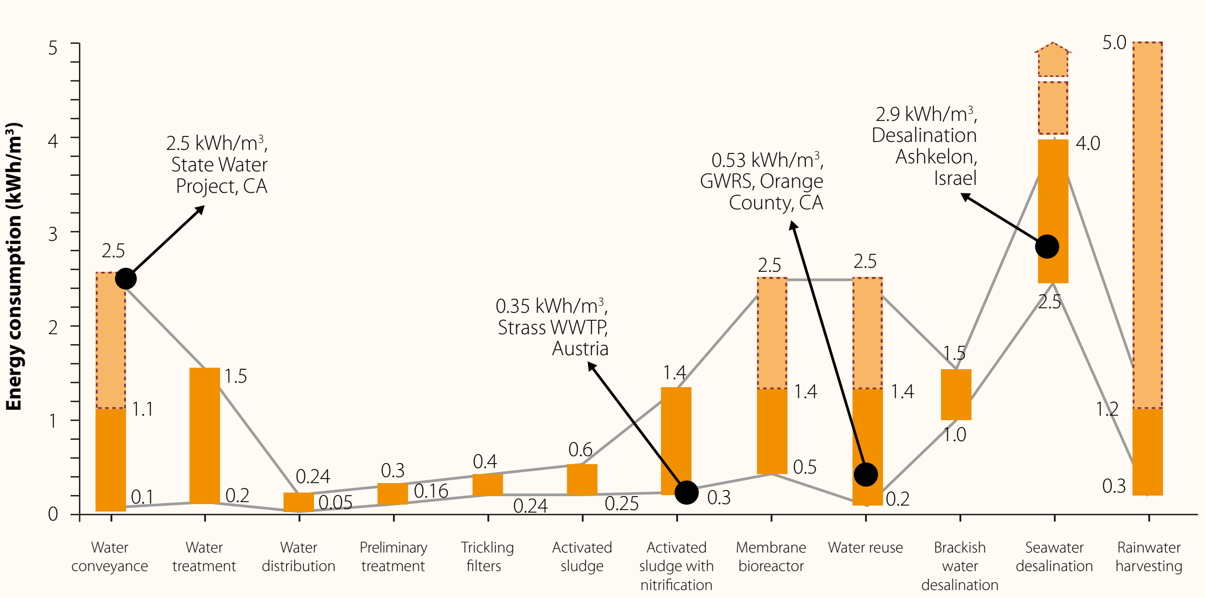
7.3 The water–energy nexus in the urban context

Water supply and wastewater management are significant consumers of energy in the urban context. The United States Environmental Protection Agency estimates that the supply of treated water and wastewater management consumes 3% of the total energy use by cities in the USA, but in some states (e.g. California) it can be as high as 20% (Novotny, 2012). The amount of energy required at each step varies significantly depending on site-specific conditions including distance to the water source, its quality (and in the case of groundwater, its depth), and the technologies used. Electricity costs are estimated at 5% to 30% of the total operating cost of water and wastewater utilities (World Bank, 2012*b*), but in some developing countries such as India and Bangladesh, it is as high as 40% of the total operating cost (Van Den Berg and Danilenko, 2011). A survey of water and wastewater management in 71 Indian cities found that electricity is the single highest cost for water utilities. In some cities, such as Jodhpur, where water is pumped and transported from the Indira Gandhi Canal more than 200 km away, electricity cost is as high as 77% of the total operating cost (Narain, 2012). As cities continue to grow, they will have to go further or dig deeper to obtain water, which will further increase demand for energy, particularly in developing countries where energy is already in short supply and in many cases expensive. Energy supply will therefore have direct implications on availability as well as affordability of water in the rapidly growing cities of developing countries in the future.

In urban water supply and wastewater management systems, water conveyance and the use of advanced water treatment options are generally the most energy intensive activities (Figure 7.3). Water reuse may also require significant energy, depending on the technology used, but this is still less energy intensive than desalination or transporting water over extremely long distances (Lazarova et al., 2012).

FIGURE 7.3

Typical energy footprint of the major steps in water cycle management with examples from different treatment plants using specific technologies



Note: GWRS, groundwater replenishment system; WWTP, wastewater treatment plant.

Source: Lazarova et al. (2012, fig. 23.1, p. 316, adapted from sources cited therein). © IWA Publishing, reproduced with permission.

Desalination is the most energy intensive water treatment technology (Section 2.3). The energy cost of treating low salinity seawater is about ten times greater than a typical freshwater source and about double the energy cost of treating wastewater for reuse (Pearce, 2012). Desalination is therefore an appropriate option only when there are no other sources or the cost of energy for transporting water is very high. As shown in Figure 7.3, even an efficient desalination plant such as the Ashkelon plant in Israel, which requires 2.9 kWh/m^3, is more energy intensive than the transportation of water over long distances in California, which requires 2.5 kWh/m^3. However, the desalination industry is working on reducing energy costs. The International Desalination Association has a goal of achieving a 20% energy reduction by 2015, and some companies have started to experiment with using renewable energy for desalination. Abengoa Water has set up a pilot plant in Spain, and Abu Dhabi's renewable energy company Masdar has announced plans to launch three new projects to test the use of renewables for desalination. By 2020, Masdar aims to have a large-scale commercial desalination plant powered by renewable sources – solar, wind or a combination thereof (Newar, 2013).

See Chapter 20 (Volume 2) for the case study 'Desalination in Gulf Cooperation Council countries'.

Once treated water is supplied to consumers, water heating may also consume large amounts of energy, particularly in cities with cold climates and in affluent cities. In Sweden, for example, it is estimated that collection, treatment and supply of water requires only about 0.46 kWh/m^3 of energy but heating water at the point of use consumes more than 100 times more energy – over 50 kWh/m^3 (Olsson, 2012). As cities become more affluent and consumers start demanding the convenience of hot water systems in their homes, the energy requirement for water supply will increase further, unless renewable energy options such as solar water heaters can be promoted.

7.4 Re-thinking urban development in terms of water and energy

As cities continue to grow rapidly, it will become increasingly difficult and energy intensive to meet the water demands of their populations and economies. Low-cost surface and groundwater sources have been depleted or contaminated in many urbanized areas (Lazarova et al., 2012). Many experts (e.g. Daigger, 2009; Novotny, 2012) agree that abstracting freshwater from a surface or groundwater source, using it, and disposing of it – known as a 'linear approach' – is not sustainable. Future urban development requires approaches that minimize resource consumption and focus on resource recovery.

See Chapter 28 (Volume 2) for the case study 'Water and energy linkage in Austin, Texas, USA'.

Novotny (2012) presents a three-phase model for the relationship between water demand and energy use (Figure 7.4). The model suggests that in the first phase, up to 65% of water demand and energy consumption could be saved in some US cities just by implementing simple water conservation measures, such as efficient water appliances, reduction in leaks and dry landscaping (i.e. xeriscaping). In the second phase, cities can augment their water supply through additional sources and treating and reusing stormwater, although this will not result in significant decrease in energy demand as in phase one. The third phase involves advanced water treatment options such as reverse osmosis water recycling systems and desalination plants. Although these advanced systems are energy intensive, they can offer a reliable source of water and their additional energy inputs may be countered by the use of efficient technology and renewable energy sources.

7.4.1 Energy efficiency in water and wastewater management

As energy cost is usually the greatest expenditure for water and wastewater utilities, water and energy audits to identify and reduce water and energy losses and

***Many experts agree** that abstracting freshwater from a surface or groundwater source, using it, and disposing of it – known as a 'linear approach' – is not sustainable. Future urban development requires approaches that minimize resource consumption and focus on resource recovery.*

enhance energy efficiency can result in substantial energy and financial savings to the utilities. The World Bank (2012*b*) estimates that technical measures to improve energy efficiency can result in 10% to 30% energy savings per measure and can have as little as a one- to five-year payback period. In 2003, the Vizianagaram Municipal Council in India introduced the concept of Watergy (energy and water efficiency), conducted energy audits of the municipal bulk water supply systems, and implemented a series of efficiency measures. The city managed to save more than 100 MWh and US$63,700 annually, while lowering energy costs by 18% and eliminating 600 tonnes of carbon dioxide emissions (UN-Habitat-IUTC, 2012).

A solar powered wastewater treatment plant under development in Los Alisos, Mexico, is expected to be energy self-sufficient.

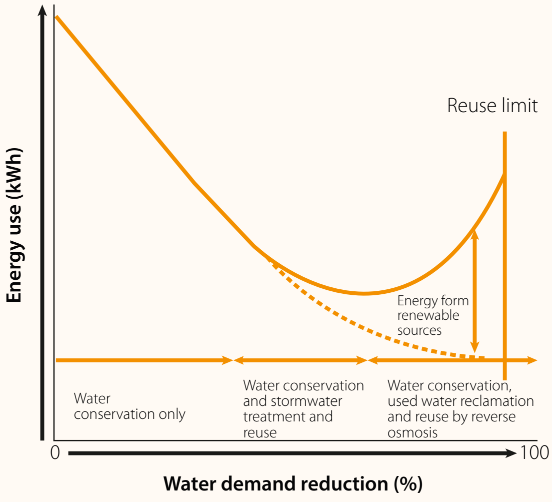
[**See Chapter 27** (Volume 2) for the case study 'Solar powered wastewater treatment plant in Mexico'.]

7.4.2 Urban planning and integrated urban water management

Water and energy consumption in cities can be reduced during early stages of urban planning through development of compact settlements and investment in systems for integrated urban water management (IUWM), such as conservation of water sources, use of multiple water sources – including rainwater harvesting, stormwater management and wastewater reuse – and treatment of water as needed rather than treatment of all water to a potable standard (Box 7.1). High density mixed land use settlements can significantly reduce water and energy consumption compared to low density land use settlements, which require large amounts of water for irrigation of outdoor landscaping and energy for transporting water and sewage over long distances.

A study on residential water use in 12 Western US cities showed that in all of the cities, more than half of the household water consumption was for outdoor irrigation. However, the community of Civano in Tucson, Arizona, has managed to reduce its use of potable water to 197 l.p.c.d. – less than half the average amount consumed by other Tucson residents – through innovative development planning and landscape design. The Civano community has smaller than average lot sizes and primarily uses native plants for landscaping, which require less irrigation water. Each house in Civano also has two water supply lines: potable water for indoor use and reclaimed water for outdoor use (WRA, 2003). As indicated in Figure 7.4, the use of water conservation measures and reclaimed water results in significant reductions in energy demand. As many cities of the future are yet to be built or are in the process of being built, better urban planning with efficient, integrated systems for urban water management and the conservation of water resources can go a long way in reducing both water and energy demand in cities (Box 7.2).

FIGURE 7.4 **A three-phase model of the water–energy nexus (without energy recovery)**



Source: Novotny (2012, fig. 3.2, p. 39). © IWA Publishing, reproduced with permission.

7.4.3 Energy from wastewater

Wastewater contains energy in the form of potential energy, thermal energy and chemically bound energy, all of which can be harnessed and utilized. The potential energy in wastewater depends on the topography's available head, or difference in height. However, even at a height of 50 m, the potential energy content of water or wastewater is only 6 kWh per capita per year (Lazarova et al., 2012). This energy source is therefore is limited to areas with favourable topography. In Amman, as the altitude difference between the city and the As-Samra wastewater treatment plant is about 100 m and the altitude difference between the plant and the outlet is 42 m, the plant is able to generate about 3 MW of electrical energy by operating two turbines before the plant and two after it. When added to what its four biogas digesters generate (Box 16.5), the plant becomes nearly energy self-sufficient (Lazarova et al., 2012). In high rise buildings, treated wastewater from the upper

7.1 BOX

Cities leading the way in water and energy conservation

Windhoek, in the heart of Namibia, the most arid country in sub-Saharan Africa, is successfully applying integrated urban water management, which includes diversifying its water sources and recycling wastewater to meet its water needs. More than 40 years ago, in 1969, the city established the Goreangab reclamation plant, which supplied 10% to 15% of the city's daily demand for potable water. In 2002, the city established another plant. Today, 26% of the water supplied in the city is recycled sewage. In 1993, Windhoek installed a dual pipe system to irrigate all municipal parks, gardens and sports fields with semi-purified sewage effluent, thus reducing potable water demand by 5% to 7%. In 1997, the city started recharging its aquifer, which enabled the city to survive for two years without any surface water. Reduction of water demand and reclamation of wastewater has enabled Windhoek to sustain its water supply system and reduce energy consumption related to transportation of water over very long distances and treatment of water from alternative sources such as seawater. From Trepper (2012) and Jacobsen et al. (2013).

Chennai, like most Indian cities, is struggling to meet the thirst of its eight million people. In the absence of perennial rivers, the city has traditionally depended on the rain that it captures in lakes, ponds and aquifers. While the city continues to keep an eye on distant rivers, it is also experimenting with innovative options such as rainwater harvesting, sewage recycling and desalination to avoid the high energy costs associated with transporting water over long distances. Following two consecutive drought years in 2002 and 2003, the city managed to develop India's most successful rainwater harvesting programme by making rainwater harvesting mandatory in all houses. It is also the first city in India to recycle sewage and has now started venturing into desalination. It is estimated that about 75% of the houses in the city now have rainwater harvesting and recharging systems and a study conducted in 2007 found that the groundwater table in the city had risen by almost 50%, from an average of 6.18 m in 2004 to an average of 3.45 m in 2007. MetroWater, Chennai's water supply and sewerage authority, earns INR120 million per year by selling sewage to the Chennai Petroleum Company, which in turn treats the sewage in its 41 million litres per day capacity reverse osmosis plant and turns it into water for its use. The company has found reclaiming sewage to be a more reliable and cost-effective option than other sources. Overall in 2008–2009, only 12% of MetroWater's total cost was for electricity, which is much lower than most other Indian cities. From Narain and Srinivasan (2012).

In 2010–2011, **Sydney** Water's renewable energy plants generated almost 15% of the utility's energy needs and it is committed to becoming carbon neutral for energy use by 2020. Sydney Water currently supports four different renewable energy technologies. Biogas is captured and converted into electricity to power its wastewater treatment plants. Similarly, treated wastewater is used to generate hydropower as it passes down a large drop shaft on its way to a deep ocean outfall. It uses photovoltaic solar energy to generate electricity and solar heaters for hot water. It also uses wind energy; the power requirements of its desalination plant are offset by the energy produced by the Capital Wind Farm near Queanbeyan. From Sydney Water (n.d.).

Source: UN-Habitat.

7.2 BOX

Conservation of water sources

In October 2012, when Hurricane Sandy swept through north-eastern USA, New Yorkers were left for days without electricity, but they continued to have access to water, thanks to New York City's efforts to invest in the Catskill/Delaware forests and wetlands instead of energy intensive water treatment plants (WWAP, 2009, ch. 14). The city saved US$4 billion to $6 billion on the cost of water treatment plants by protecting forests and compensating farmers in the Catskill Mountains for reducing pollution in lakes and streams (Leahy, 2013). More than 200 cities and regions around the world have invested in conserving their watersheds and using natural infrastructure to provide essential ecosystem services. In 2011, more than $US8 billion was invested globally in watershed projects; China led the way with 91% of this sum (Bennett et al., 2013). Investment in watersheds ensures regular supply of freshwater and reduces the need to invest in expensive and energy intensive alternative sources. As conveyance over long distances and use of advance water treatment are the most energy intensive components of water and wastewater management systems, the application of integrated urban water management options such as watershed management results in reduced energy demand.

Source: UN-Habitat.

floors or collected rainwater from the roof can be used in the lower floors to minimize energy required for pumping of freshwater.

The thermal energy in wastewater comes from its temperature when leaving a building – about 27°C for mixed wastewater and 38–40°C for grey water (Roest et al., 2010). The thermal energy of wastewater is particularly useful in places where a large amount of energy is required for heating water, because it can be used to preheat the water via heat exchangers or heat pumps. In Dalian, a city of 5.7 million people in north-east China (recognized as a National Model City in Environmental Protection by the Chinese government), heat is reclaimed from sewage to meet part of the heating and cooling requirements of the Xinghai Bay Business District. Authorities claim they save more than 30% in energy compared to conventional solutions (Friotherm, 2012).

The chemically bound energy in wastewater results from its carbon content, which can be converted to methane under anaerobic conditions. The methane can then be used for cooking and heating, converted to electricity, or used to fuel vehicles. Based on the maximum chemical oxygen demand (COD) load per capita of 110–120 mg/L, Lazarova et al. (2012) estimates the maximum theoretical chemical energy content of wastewater to be 146 kWh per capita per year. Although the chemically bound energy content in wastewater is less than its thermal energy, it can be transported without much loss, whereas the thermal energy has to be reclaimed as close to the source as possible. Many wastewater treatment plants have been able to generate biogas from wastewater or sludge and convert it to heat or electricity. In Stockholm, for example, public buses, waste collection trucks and taxis run on biogas produced from sewage treatment plants (Osterlin, 2012) (see Chapters 17 and 24 [Volume 2], for the case studies 'Green energy generation in Vienna, Austria' and 'Green energy production from municipal sewage sludge in Japan', respectively).

In developing countries, particularly in warm climates, there is little opportunity for using thermal energy from wastewater, but generating biogas from wastewater can be very useful. This is now a widespread practice in many cities in Africa and in Asia. More than 300 households and institutions in Maseru, Lesotho, are generating biogas from wastewater and using it as a cooking fuel. Although the initial cost for decentralized wastewater treatment systems – which includes a biogas digester, an anaerobic baffle reactor and planted gravel filters – is slightly higher than septic tanks, the additional benefits of biogas allow the system to pay for itself in three years (Mantopi and Huba, 2011). When biogas is used for cooking it often replaces inefficient and potentially harmful solid biomass fuels (Chapters 3, 9). Decentralized biogas systems for wastewater treatment also reduce the cost of transporting and pumping wastewater.

Another potential option for energy production is the use of dried faecal sludge (FS) as fuel. Nakato et al. (2012) analysed FS samples from three cities (Dakar, Senegal; Kampala, Uganda; Kumasi, Ghana) and found the average calorific value of the samples to be 17.2 MJ/kg dry solids (DS), which is comparable to other commonly used fuels such as rice husk (15.6 MJ/kg DS), forest residue (19.5 MJ/kg DS), coffee husk (19.8 MJ/kg DS) and sawdust (20.9 MJ/kg DS).[19] The study found that the FS must be dried to ≥27% DS to enable industry to derive the net energy of 17.2 MJ/kg DS. Experience from Uganda has shown that it is possible to achieve a DS concentration of more than 30% by drying the FS in simple drying beds for two weeks, thus indicating that additional energy inputs would not be required.

7.4.4 Waterborne transit

Many urban areas are located next to large water bodies, making waterborne transit another area where water and energy come together in the urban context. Several studies have shown that waterborne transit is one of the most energy efficient means of transport. Studies done in the USA indicate that inland towing barges are more than three times more energy efficient than road (trucks) and 40% more efficient than rail in transporting cargo (PIANC, 2011). A study done by India's National Transport Policy Committee (1980) showed that the energy consumption of transporting goods by barge was 328.0 BTU per tonne-km,[20] whereas for diesel trucks it was five times higher at 1587.3 BTU per tonne-km. As transportation is one of the most energy intensive sectors in the urban context, increasing the use of waterways for passenger or goods transit can lead to substantial energy savings.

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[19] 1 MJ = 0.278 kWh.

[20] 1 BTU = 0.293 Wh.

CHAPTER 8

Industry

UNIDO

Water Management Unit (UNIDO) and John Payne (SNC Lavalin)

8.1 The relationship of water and energy with industry

In its internal operations and with its external reach, industry both uses and abuses water and, in so doing, consumes energy. Industry seeks water and energy efficiency though the two are not always compatible and there are trade-offs to be made. Efficiencies are usually driven in terms of cost–benefit as they relate to company profits, although government policy and legislation can significantly influence the situation. When these efficiencies translate to reduced water and energy use in a plant, one potential result is a reduction in water and energy stress outside the factory walls in the communities and river basins where it operates. In addition to the use (and therefore the cost and economics) of water and energy along supply and value chains (WWAP, 2012, ch. 20), there is an increasing trend towards corporate social responsibility (CSR) and a company's licence to operate, linked with broader public policy and legislation. Many industries see their direct interaction with water and energy occurring primarily at a plant or factory level, yet the value chain approach is increasingly used by several multinationals, and incorporated into their risk assessment and risk management strategies. At the end use level, water is used in a variety of ways – as a raw material, for steam, for heating and cooling, as a solvent, for cleaning, and for transport of waste and particulates. Energy is further required to move, heat, cool, treat, discharge or recycle the water. Water consumption and efficiency is therefore an important determinant in energy efficiency (UNIDO, 2011). Industry uses energy independently of water as well; for example, to power machinery and equipment, and to heat and cool buildings. Energy is used outside production and manufacturing, for example in transporting goods.

Water footprints often capture external or indirect factors, such as industry's indirect relationship with embedded water to produce energy used in its facilities. Virtual water is found in the supply chains of materials and equipment employed by industry and in the downstream use of products by consumers, which use energy as well. Such factors have a broader reach outside the manufacturing or production process. There is a relationship of water and energy with industry both in and out of the 'water box' (WWAP, 2009).

8.2 The status of water and energy in industry

The separate means by which water use and energy consumption are managed in industry generates information and data relating to each sector's individual use and efficiency, but essentially no linkage between the two. Information on a worldwide scale is generalized and is influenced by industrialized nations, such as those in the OECD, and by emerging industrial countries, such as China and India. Useful data from individual countries illustrate some general points and trends as do detailed data within individual sectors and companies. However, there is a need to relate water and energy indicators to one another.

8.2.1 Amounts and trends

Industry uses proportionately significantly more of the energy supply than it does of the water supply. The industrial sector accounts for about 37% of primary global energy use (UNIDO, 2008). Within this sector in 2010, five principal energy intensive industries accounted for about 50% of that use: chemicals (19%), iron and steel (15%), non-metallic minerals (7%), pulp and paper (3%) and non-ferrous metals (2%) (US EIA, 2013). Worldwide, industry accounts for 19% of all water withdrawals, but with big regional variations: 2% in South Asia and 77% in Western Europe (FAO AQUASTAT, n.d.). In England and Wales, the manufacturing sector is the largest user of water, with 45% to 55% of the directly abstracted volume from non-tidal sources, excluding major non-consumptive use. The top five abstraction categories were chemicals and chemical products, basic metals, paper and paper products, beverages, and food products – a noticeable overlap with the energy intensive industries noted above (WRAP, 2011).

World energy consumption increased by 186% between 1973 and 2010 and for the same period industry's use increased by 157% (IEA, 2012*c*). The IEA predicts that global energy demand will increase by about one-third by 2035, with the non-OECD component increasing to 65% (IEA, 2012*a*), indicating that the amount of industrial energy use varies with the type of economy. The OECD predicts that by 2050 global water demand will increase by 55% and within that, manufacturing's share, though not the largest, will increase by 400%, with the largest component coming from the BRICS countries (OECD, 2012*b*). For Asia, a 65% increase in industrial water use is forecast between 2000 and 2030 (WEF, 2009).

8.2.2 Water quality and energy

Different industrial processes are able to use water of varying quality. Not all industrial production requires the ultra-pure water of the semiconductor industry or the high quality raw-material water of the food and beverage industry. However, some water treatment is required for cooling, condensing and steam. Further treatment is required for discharge: for example, in Canada, 38% of discharged industrial water is not treated, while 16%, 37% and 8% underwent primary, secondary or tertiary treatment, respectively (Statistics Canada, 2009). Industry can recycle its own water in heating and cooling, and may use reclaimed water from sources such as urban water supplies instead of freshwater abstraction. Specific industries report some water recycling data and, while global statistics are not widely available, it is reported that recirculated (recycled) water use, as a percentage of intake, is 53% in the Canadian manufacturing industry (Statistics Canada, 2009).[21] Water treatment requires energy, and the amount of treatment needed increases as the quality of the source decreases. As shown in Figure 2.2 (Section 2.3), approximately twice as much energy is required to deliver treated water from wastewater as from a lake or river. For industry, the implication is that in terms of energy required, it may be more economical to extract water directly from a raw external source or treat wastewater to minimum standards for discharge, than to fully treat wastewater for reuse.

8.2.3 Industry in low income countries

Globalization has led several manufacturing industries to move to lower income countries. Drivers for this trend have commonly been cheaper labour, favourable taxation, and less or lighter regulation and enforcement. Water intensive industries in regions with adequate water may be transferred to areas with less water, stressing local water supplies and local utilities (WWAP, 2003). New industry may contaminate vulnerable water supplies with

BOX 8.1

Trends in water and energy use in tourism

Tourism is one of the most promising drivers of growth for the world economy, but its development is accompanied by sustainability-related challenges. An investment of 0.2% of current global Gross Domestic Product (US$135 billion) per year between now and 2050 would allow the tourism sector to grow steadily, contributing to economic growth, employment and development while ensuring significant environmental benefits such as reductions in water consumption (18%), energy use (44%) and carbon dioxide emissions (52%) compared with a business-as-usual scenario (UNEP/UNWTO, 2012).

To mobilize and maximize this tourism investment, small and medium-sized tourism enterprises need better access to tools and financing from governments and international organizations through public–private partnerships. Public policies and support such as subsidies to encourage private investment in green tourism would provide the conditions for the further development of sustainable tourism. Destination planning and development strategies are the first step towards the greening of tourism (UNEP/UNWTO, 2012).

Initiatives such as the Hotel Energy Solutions (HES) project, initiated by UNWTO with the support of the European Union 'Intelligent Energy Europe Programme' and in close partnership with UNEP, IH&RA, EREC and ADEME, aim to increase energy efficiency in small and medium-sized hotels by 20% and increase their use of renewable energies by 10%, demonstrating that economic growth and sustainability can, and should, go hand in hand. The project helps to reduce hotel operational costs while increasing competitiveness and sustainability and assisting in alleviating the industry's impact on climate change. Its principal asset is easy-to-use software – the HES E-toolkit – which allows hoteliers to assess current energy use and decide on the most advantageous technology investment solutions.

Source: UNWTO.

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[21] Similar statistics are not generally available for developing countries, and even for OECD countries, details of how much industrial water is treated and recycled are difficult to obtain.

industrial waste. The combined effect of these stresses may impose barriers on the transfer of certain manufacturing activities to low income countries. Services such as The Global Water Tool (WBCSD, n.d.) are available to assist companies in evaluating the risks involved. In developed countries, industrial water use may be stabilizing due to increased efficiency and the move of some manufacturing plants to low income countries yet, at the same time, lack of access to water may hinder such moves, especially for water-dependent industries (Goldman Sachs, 2008). It is significant to note that 60% of the world's industrial energy consumption is estimated to occur in developing countries and transitional economies (UNIDO, 2010).

8.2.4 Private enterprise

Large companies and multinationals, particularly in the food and beverage sector, have been engaged for some time in improving water and energy efficiencies. One estimate suggests that the combined direct year's consumption of five of the large food and beverage companies is enough to provide the basic water needs of the world's population for one day (JPMorgan, 2008). Such companies often see the value of efficiencies in both monetary and societal terms. Nestlé, for example, has reduced its water use from 5 to 1.8 litres per dollar of sales over a ten-year period (McKinsey & Company, 2009*a*) and promotes CSR values (Nestlé Waters, n.d.). Other companies, such as those in the mining sector, are less advanced in achieving efficiency, as water is seen more as a compliance issue than a strategic resource (Sarni and Stanislaw, 2012).

Small and medium-sized enterprises (SMEs) with 20 or fewer employees comprise more than 70% of enterprises in most economies (OECD, 2013*a*). They employ between 9% (USA) and 35% (Greece) of the workforce (OECD, 2013*a*), and figures from non-OECD countries are likely to be higher. Although SMEs as a group have the potential for making a significant impact on water and energy efficiencies, that impact is mostly apparent on a local scale. SMEs are commonly in need of equity capital and have fewer resources to improve efficiencies. Monetary assistance from financial institutions and expertise and capacity-building support may have catalysing impacts (e.g. UNIDO's TEST programme, Box 16.4).

Tourism, a major economic sector in many small developing countries, is affected by a set of unique challenges with respect to water and energy. Efforts are currently under way to increase the level of sustainability in industry operations (Box 8.1).'

8.3 Water and energy metrics in industry

Efficiency and improvement in water and energy need to be measured for benchmarking and future evaluation. Separate data and indicators are available for both water and energy use in industry. Industry is interested in measuring the cost effects on its profitability whereas governments and civil society are more focused on overall economic results, social benefits and the environment. Metrics comparing water and energy use to indicate the effects of one upon the other, both at plant scale and for countries as a whole, are necessary yet seemingly absent.

> ***In developed countries, industrial water use*** *may be stabilizing due to increased efficiency and the move of some manufacturing plants to low income countries yet, at the same time, lack of access to water may hinder such moves, especially for water-dependent industries*

Water and energy audits are a starting point to benchmark a facility's status, measure usage and identify areas for improvement. This information can be used to compile water and energy footprints. A water footprint is 'the total volume of water used in the production of the goods and services consumed by an individual or community or produced by a business' (WWAP, 2009, p. 101) and is usually quoted in terms of cubic metres of water per unit product. It is closely connected to the concept of virtual water, which is the 'volume of water required to produce a commodity or service' (Hoekstra and Chapagain, 2007, p. 36). This is an economic concept: the water embedded in traded goods. Virtual water is commonly presented in terms of litres of water per kilogram (WBCSD, 2006). Energy footprints, on the other hand, map energy flows from supply to end use; common examples for manufacturing sectors have been produced (US DOE, n.d.). These footprints indicate primary energy flow from both off-site and on-site (Figure 8.1) and the distribution of energy to on-site end uses.

Other measures include water productivity, the monetary value of the product for each cubic metre of water used, and energy intensity, expressed in terms of energy use per monetary unit, such as per unit of value added (UNIDO, 2010) or the amount of energy used to produce one unit of a commodity (UNIDO, 2008).

8.4 Forces influencing the use of water and energy in industry

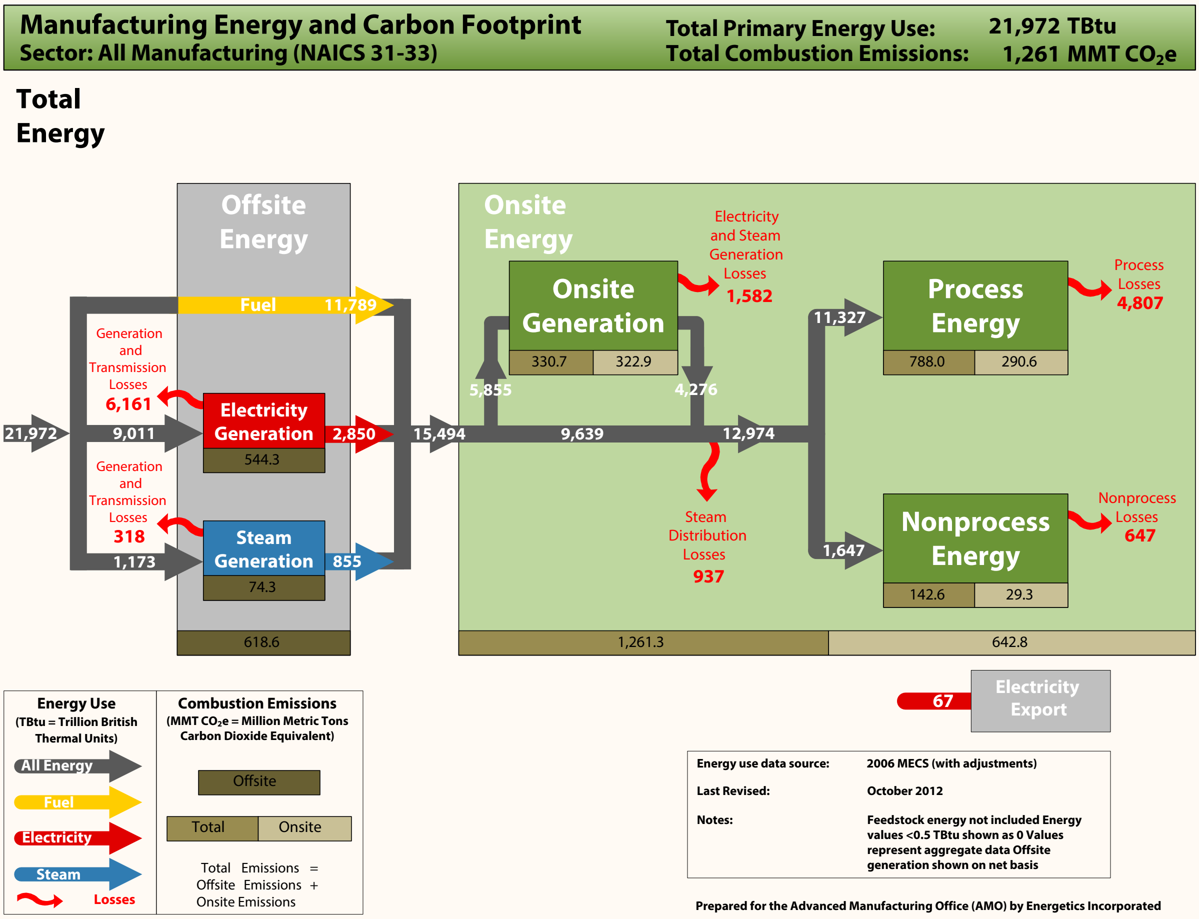
As described in Sections 2.1 and 3.1 of this report, water and energy have many of the same demand drivers. Principal among these are population growth, economic development and urbanization, and a growing middle class (Sarni and Stanislaw, 2012). Overarching these drivers is the challenge of policy and governance and their resulting fiscal and legal drivers. In the decision-making process for industrial location, water and energy needs compete for priority not just with each other but also with factors such as labour costs, availability of skilled labour, and access to raw materials, markets, suppliers, transportation, infrastructure, regulatory frameworks and centres of innovation (McKinsey & Company, 2012).

8.4.1 Population pressure and living standards

Population growth and poverty reduction produce increased demands for water and manufactured goods, which means increased demand for energy, mainly as electricity. This trite point underlies many drivers that put demand pressure on water and energy. Globally, manufacturing output continues to grow in advanced economies by about 2.7% annually and by 7.4% in large developing economies (McKinsey & Company, 2012). Per capita use of water tends to increase with the higher standards of living associated with rising levels of industrial activity in developing countries (Goldman Sachs, 2008). The case is similar for energy. In developing countries, the growing industrial sector requires increasing energy – already more than 50% of the energy supply (UNIDO, 2008).

8.1 FIGURE

Primary energy use: All USA manufacturing



Source: US DOE (n.d.).

8.4.2 Economic forces

Although supply and demand are fundamental parameters, they are influenced by factors other than the amounts of water and energy involved. Perhaps the most significant of these is price. Although there is wide variation, water prices for domestic use in the OECD are generally higher than for industry and agriculture (CWF, 2011) (Table 8.1). Electricity prices per megawatt-hour for industry range from US$69.57 (USA) to US$279.31 (Italy) (IEA, 2012*c*). Again, domestic prices are significantly higher in all countries, although prices between countries are not always comparable, as they are not related to disposable incomes or GDP (CWF, 2011).

Water and energy prices are strongly affected by subsidies that support industry and its competitiveness. These subsidies distort the true economic relationship between water and energy. Particularly for water, price is not a true reflection of cost and may in fact be less than the cost. Historically, the price of water has been so low that there has been no incentive to save it (TSG, 2012). There is growing momentum for water prices to reflect its true cost, which, it is hoped, can reduce consumption and encourage conservation and efficiency. Demand elasticity can allow industry to adapt to conservation-minded pricing over the long term, especially in those industries with high water use (Goldman Sachs, 2008). The assumption that lower energy prices will lead to higher specific energy consumption (SEC) and vice versa has been shown in only a few industries. Higher SEC is related to other factors such as keeping old, less efficient machinery to avoid the high investment in newer, more efficient equipment during uncertain economic times. Where local energy is relatively cheap, for example in major fossil-fuel producing countries such as Russia, Saudi Arabia and South Africa, there is little incentive to reduce energy use (UNIDO, 2010).

Volatility in energy prices affects industry more than the availability of energy. The reverse is somewhat true for water – availability of water is a bigger business risk – as the price is generally low and stable. Oil has shown a price variation of 42.9% since 1989 whereas the same figure for water is 4.2% (WEF, 2009). Water prices are capped because the service is generally publicly run or regulated (WEF, 2009), at least in developed countries (Section 1.3).

8.4.3 Availability and security

Access to water, competition for water and water security are expressions of water availability and the need to obtain

TABLE 8.1 **OECD estimates of prices for water by broad sector usage**

OECD nation	Household water supply	Industrial and commercial	Irrigation and agriculture	Average price of water supply
Netherlands	3.16	1.08	1.44	1.89
Austria	1.05	1.05	1.01	1.04
France	3.11	0.95	0.08	1.38
Greece	1.14	1.14	0.05	0.78
Spain	1.07	1.08	0.05	0.73
United States of America	1.25	0.51	0.05	0.60
Hungary	0.45	1.54	0.03	0.67
United Kingdom	2.28	1.68	0.02	1.33
Australia	1.64	1.64	0.02	1.10
Portugal	1.00	1.26	0.02	0.76
Turkey	1.51	1.68	0.01	1.07
Canada	0.70	1.59	0.01	0.77

Note: Data not available for all Organisation for Economic Co-operation and Development (OECD) member nations. Prices are in US$/m^3 water. Includes water supply only and excludes wastewater charges and taxes.
Source: CWF (2011, fig. 9, p. 8, derived from source cited therein).

adequate supplies. These issues are growing in importance as industry grows in (or moves to) lower income countries that are frequently water stressed. The challenge is to prioritize and satisfy basic local water requirements ahead of those of industry. Water needs to be provided at an affordable cost to the population (and at no cost to those who cannot afford it) for meeting basic domestic needs, but could perhaps be provided at a premium for industry. While quantity is often the focus of water security, quality issues can be as important. Contaminated and untreated water effectively reduces the water supply, notwithstanding the pollution it causes. All of these risks can extend to the supply chain.

Energy security is dependent not only on supply but also, importantly, on access (WEF, 2012*a*). Reliability of transmission and distribution systems for electricity, including risks related to disruptions to supply (especially in countries with a limited range of energy sources) and relations between nations and trading partners raise significant concerns for industry, especially with respect to price volatility. As with water, there is an interaction with the MDG of universal access to energy in lower income countries where access is non-existent or energy costs are prohibitive.

8.4.4 Governance and policy-making

Governments and their policies are the principal enablers for water and energy efficiency. There is frequently a lack of coordination and collaboration between policy- and decision-makers in the realms of energy and water. There is a common perception that energy efficiency is too complex for public policy, and that it is best resolved in the marketplace (UNIDO, 2008). As industry is primarily focused on production, its interest is to secure water and energy at the lowest prices and not necessarily within a programme of water and energy efficiency. This provides an opportunity for policy intervention (UNIDO, 2008).

> ***As industry is primarily focused on production,*** *its interest is to secure water and energy at the lowest prices and not necessarily within a programme of water and energy efficiency. This provides an opportunity for policy intervention.*

The challenge is to develop a sustainable approach to policy intervention. Manufacturing has traditionally been considered in terms of a vector for mass employment, but it also is 'a critical driver of innovation, productivity and competitiveness' (McKinsey & Company, 2012, p. 15). Policy-makers need to understand the diversity of industry and its position in the wider national and regional economy. In the case of energy, governments need to be aware of industries affected by energy costs, the impacts of energy costs, and what might drive location (McKinsey & Company, 2012). Similar points may apply to water use in terms of affordable access to reliable supply and treatment services. However, cost and other market considerations are often not as prominent as the overall availability of water resources, especially for larger plants that may have their own water supply and treatment facilities.

8.4.5 Legislation and regulation

Energy regulation is more directed towards production and distribution than use in industry, although in many industries, energy efficiency is driven by regulations concerning carbon footprints and GHGs. For water resources, regulation generally concerns use and discharge. For example, the USA's Clean Water Act protects surface water from pollution discharges and the EU Urban Wastewater directive is aimed in part at industrial wastewater. Overall there appears to be an increase in water regulation facing industry: this increases cost and may jeopardize predictable supply (JPMorgan, 2008).

Laws and regulation can be effective drivers of efficiency, and they are often based on both offering incentives and threatening penalties. A less forceful method is to use voluntary guidelines. Regulation is becoming more global; for example, China is mirroring much of the USA's regulatory framework with its State Environmental Protection Agency (SEPA) (Goldman Sachs, 2008). In contrast, better use of energy and water in lower income countries may be the indirect result of regulations in developed countries with markets and companies that are subject to higher environmental standards (WWAP, 2012). This must be seen in the context that an estimated 70% of industrial waste (and 90% of sewage) is discharged without treatment into usable water supplies in developing countries (UN, 2003).

Enforcement of regulation can be a challenge, especially in countries with limited resources. The goal is that regulations must be clear and based on the latest information and science. Industry is susceptible to changes in rules and regulations whether they are unexpected or the result of political changes.

Regulators and organizations are working on ways for companies to calculate and disclose their water and energy footprints and efficiencies and these efforts could lead to industry rankings, adding leverage regarding reputational risk. Many organizations, such as the WWF, the UN CEO Water Mandate and the Alliance for Water Stewardship, are working to increase the awareness, leadership and engagement of the private sector so that companies consider more fully the water risks they face – physical, regulatory and reputational. On a global scale, the recently designed Energy Architecture Performance Index is a tool designed for policy- and decision-makers to manage and monitor the challenges associated with the transition to 'a new energy architecture' (WEF, 2012*b*, p. 8). It measures energy's contribution to the economy, sustainability, and access and security, ranking countries accordingly.

8.5 Opportunities and trade-offs

The private management structure of industry gives it the flexibility to effect changes, which can be rapid, and improve efficiency in water and energy use within itself and its immediate sphere of influence – working from inside the water and energy 'boxes'. For governments and regulators, outside-the-box opportunities exist to provide enabling environments and institutional frameworks to assist industry efforts.

Opportunities for energy efficiency in industry have existed for a long time. Beyond the quest for more cost-efficient energy use, the most recent driver is the emphasis on climate change, where a reduction in GHG emissions is strongly linked to energy use and efficiency. Water use and efficiency opportunities are now following suit, driven in part by climate change and the scarcity of water resources it is projected to produce. However, there may be a rebound effect. Although energy efficiency means the same production can be delivered with less energy, it also means more can be produced with the same amount of energy. The same effect can be true for water (Ercin and Hoekstra, 2012).

New and developing technology is available to improve industry water productivity and energy efficiency. While it is often the case that more efficient or less use of water translates into energy savings because of the need to heat, cool, move and treat water, the opposite is less likely to be the case – that more efficient use of energy means less use of water (unless embedded water to produce the energy is factored in). Closed-loop dry cooling systems are an example of both water and energy savings combined.

> ***Enforcement of regulation** can be a challenge, especially in countries with limited resources. The goal is that regulations must be clear and based on the latest information and science.*

In most cases, the main trade-offs are whether energy savings trump water savings (or vice versa), and whether gaining an improvement in water can come at the expense of energy (or vice versa). This is where water productivity intersects with energy efficiency. For example, alternative tailing disposal (ATD) mining techniques may reduce water use but they require more energy to dewater and transport the filtered, thickened or paste-like material (Watson, 2010). Recycling water is strongly encouraged yet the energy used for treatment per cubic metre is considerably more than that for supplying fresh water (Figure 2.2). These trade-offs highlight the need for balanced optimization, as industry is concerned with its overall costs. Such cost–benefit interactions are easiest to measure at the plant level. In the short term, investments may be perceived as a high and risky cost in the light of longer term gains such as lower operation and maintenance costs. But many investments in water productivity have shown positive returns in as little as three years (McKinsey & Company, 2009*b*).

Industry must consider the full range of inputs in the trade-off between where products are produced and where they are sold (McKinsey & Company, 2012). Trade-offs are made not only between water and energy but between both of them in regards to labour availability, raw materials, transportation, markets and so on. Industry's priority is productivity, so compromises will be made in business interests, and water and energy efficiencies have to be optimized under the specific circumstances. Capital for investment is frequently limited and industry

In the short term, *investments may be perceived as a high and risky cost in the light of longer term gains such as lower operation and maintenance costs. But many investments in water productivity have shown positive returns in as little as three years.*

may choose to expand capacity, which will generate more revenue, rather than improve efficiency (UNIDO, 2010). The opportunities in energy savings in industry translate to a potential 26% improvement worldwide based on benchmark data, and more than 75% in developing countries or economies in transition. This would result in a saving of 3% to 4% in total cost of production (UNIDO, 2010).

Trade-offs may be difficult to see in monetary terms as a return on investment. When a company sees the opportunity to adopt new paradigms of CSR and commits to cleaner production and sustainability, there is a financial investment of time and materials. While this may lead to more profit, which is one measure, it is also intended to improve the company's social licence to operate, which is intangible, like goodwill.

Government and decision-makers are also faced with trade-offs, which are very different to those of industry because their constituency has many stakeholders with competing interests. In theory, IWRM takes account of industry's requirements, balanced with the needs and interests of affected stakeholders and environmental concerns. Trade-offs are bound to be necessary, and dealing with them needs to be based on good data in the bigger picture. Industry generally recognizes that regulation will shape water economics and that regulators' preferences can shape responses (McKinsey, 2009*b*). The same is also likely true for energy.

CHAPTER 9

Ecosystems

UNEP

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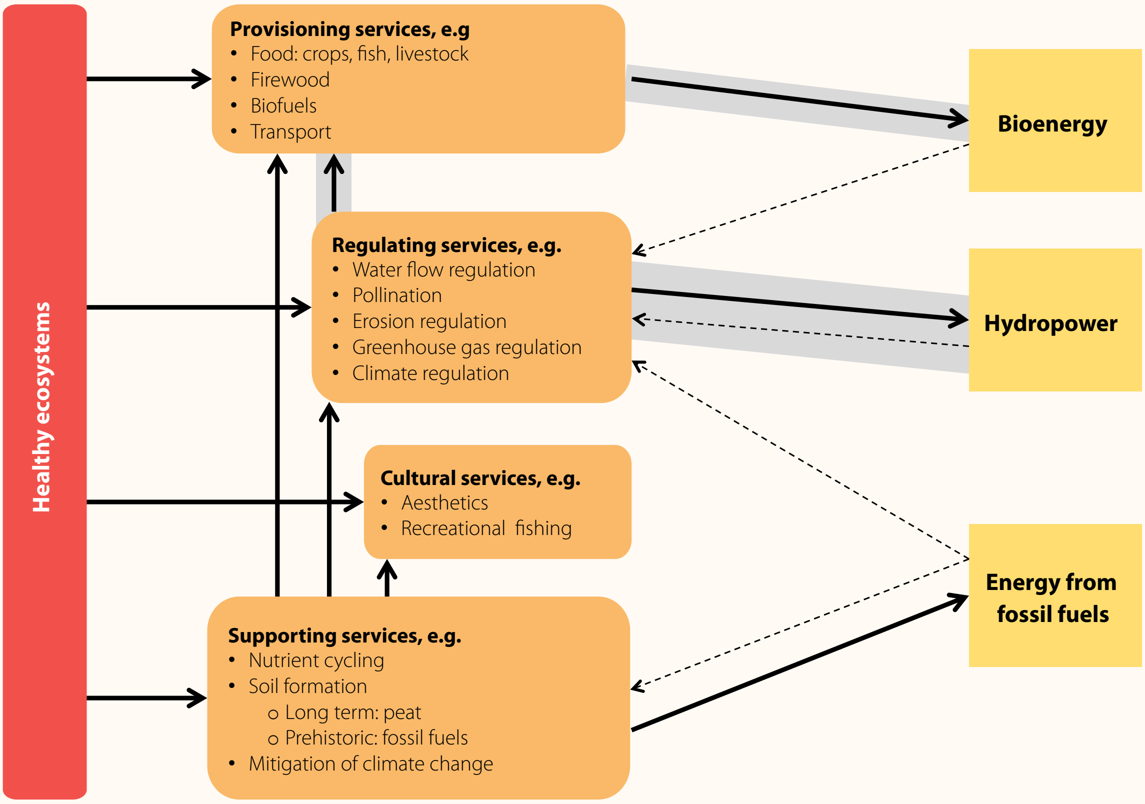
9.1 Ecosystems as the foundation of the water–energy nexus

The availability of adequate quantities of water, of sufficient quality, depends on healthy ecosystems and can be considered an ecosystem service (UNEP, 2011*a*). Looking at the world as a range of ecosystems (from pristine nature to intensive agriculture) and recognizing that ecosystems provide a variety of services to the water–energy nexus can help the management of trade-offs and ensure that short-term gains (e.g. in providing energy) do not undermine services critical for resilience and long-term environmental sustainability (Boelee et al., 2011). Maintaining environmental flows enables important ecosystem services that are fundamental to sustainable economic growth, human well-being and societal peace in shared river basins (UNEP-IRP, in press).

Ecosystems provide the enabling environment for water flows as well as energy provision, and are impacted by many processes across the water–energy nexus. Where water is a source of energy, be it directly (e.g. hydropower) or indirectly (e.g. irrigated biofuels), healthy ecosystems

FIGURE 9.1

Simplified diagram of some major interlinkages between ecosystem services, energy and water



Note: Bold arrows indicate a major dependency; dashed arrows indicate major, usually negative, impacts; and shading indicates that water flows play a crucial role in these interactions. Categories of ecosystem services are according to MEA (2005).
Source: UNEP.

deliver the services to sustain the production of that energy (Figure 9.1). At the same time, energy generation has an impact on ecosystems both directly (e.g. mining of fossil fuels in forested areas) and through the use of water for energy (e.g. hydropower dams that alter river ecology).

9.2 Energy, water and ecosystems: Dependencies and impacts

Links between energy production, water and ecosystems are manifold (Table 9.1). Power generation plants are often located near rivers, as they require a regular supply of freshwater for cooling, and in the case of hydropower, water is used to drive electricity-generating turbines. The waste and warm water generated in thermal power plants can be treated by ecosystems through in-stream processes involving absorption, buffering, dilution and detoxification.

At the same time, ecosystem services are being compromised worldwide, and energy production is one of the drivers of this process (WWF, 2012). Different forms of energy have, to a greater or lesser extent, an impact on water resources (Table 9.1). These impacts can be easier quantified and understood at smaller spatial scales due to the nature of water resources and the boundaries of water flows (GEA, 2012). Most energy production is heavily

9.1 TABLE

Examples of water use for energy production and the related ecosystem services

Type of energy source	Example of water use	Ecosystem services	
		Depends on	**Impacts on**
Hydropower	Electricity generation	Water flow regulation upstream (R) Erosion regulation upstream (R) Climate regulation (S)	Fisheries (P) Water flow regulation downstream (R) Sediment transport downstream (S) Recreation (C)
Bioenergy	Water use for irrigation of biofuel crops Water used for biomass	Water supply (P) Water flow regulation (R) Soil fertility (S) Pollination (R)	Water flow regulation (R) Food production (P) Water quality (P)
Fossil fuels	Extraction (e.g. exploration, hydraulic fracturing, shale processing, drilling equipment, dust suppression)	Long-term soil formation (S)	Nutrient cycling (S) Landscape (C) Erosion (R)
	Refining (e.g. coal washing, oil hydrogenation, gas purification)	Water flow regulation (R)	GHG regulation (R)
	Use		GHG emissions (R)
Thermal power generation (fossil, nuclear, concentrated solar power)	Cooling	Water flow regulation (R)	Biodiversity (R) Aquatic ecosystem functions
	Waste disposal		Almost all regulating and supporting services

Ecosystem services: C, cultural; P, provisioning; R, regulating; S, supporting. GHG, greenhouse gas.
Source: UNEP.

dependent on readily available water (Chapter 3), and this dependency impacts water-related ecosystems in a variety of ways. If adequate water is not available at the right place at the right time and in the right quantity and quality, ecosystem functions and services, and subsequently energy production, can be negatively affected.

Life-cycle environmental impact assessment (EIA) methods are available to quantify and rank impacts of various types of energy generation. Water consumption often is included into these methods, though environmental impacts of water use can also be determined. A focus on ecosystem services in EIA can help the approach move beyond impact assessment towards a comparison of options; for example, various biofuel crops, to determine which is most sustainable (Coleby et al., 2012). Funding organizations such as the World Bank emphasize the need to match development with environmental sustainability, such as green growth in the energy sector (World Bank, 2013*b*).

9.2.1 Hydropower

Hydropower is the largest renewable source of electricity generation (Figure 3.5), and although it uses water flows as the source of energy, most of the water that passes through hydropower plants can be used for other purposes afterwards (Section 3.3.3). Large dams are often built to create reservoirs, the functioning of which relies on vegetation and healthy soils upstream to protect the reservoir from sedimentation and regulate the flow of water to it. Many well-designed and operated reservoirs include catchment management.

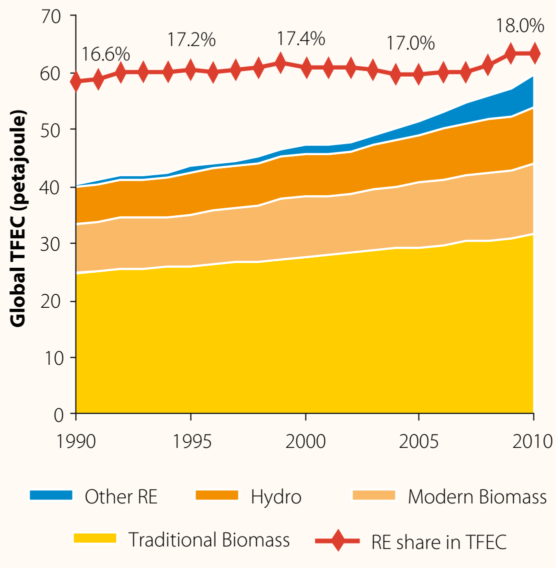
From an environmental perspective, an important issue in hydropower generation, as for dams and reservoirs in general, is the fragmentation of river systems with far-reaching impacts on ecosystem services that benefit human activities, economies and development (GEA, 2012). A recent global assessment indicates that of the 292 large rivers studied, 172 are already seriously affected and fragmented by dams (Nilsson et al., 2005), obstructing upstream and downstream fish migration. Damming for power production and artificial regulation of flows can affect the timing of water flows: often it reduces or eliminates seasonal floods and negatively affects river ecology, adjacent floodplains and wetlands. This in turn has an impact on the breeding grounds of aquatic species (affecting protein stock and fisheries), groundwater recharge, soil fertility, agricultural productivity, biodiversity and water quality (e.g. Herath et al., 2011; Opperman et al., 2011; see also Section 6.2). Another impact of dams is the reduced levels of sediments transported downstream, which undermines coastal ecosystem integrity through loss of the land-stabilizing benefits of healthy sediment flows. In some cases, this could increase vulnerability to storm events. Globally, dams in river systems are estimated to trap 4–5 Gt/year (Vörösmarty et al., 2003), or approximately 25%, of total sediment transport (GEA, 2012).

9.2.2 Bioenergy

Bioenergy refers to the renewable energy derived from biomass or biological sources, such as firewood, biofuels, agricultural by-products, charcoal, peat and dung. Globally, renewables (including hydropower) account for 18% of the primary energy used in the world (Figure 9.2). Bioenergy dominates, accounting for 78% of renewables (14.1% of the total), the majority of which comes from traditional biomass (68% of bioenergy) (Banerjee et al., 2013). More than two billion people in the world rely on firewood and charcoal for their daily energy needs (REN21, 2012) (Table 1.1). When used for cooking indoors, this leads to high levels of indoor air pollution, affecting particularly poor women and children (Section 1.1). Biomass is also used on a larger scale for the generation of electricity in power plants consuming wood chips and forest residues (Figure 9.2).

FIGURE 9.2

Global total final energy consumption (TFEC) versus share of renewable energy (RE)



Source: Banerjee et al. (2013, fig. 4.5, p. 209, based on IEA data cited therein). © World Bank, Washington, DC.

Regardless of scale and type, all forms of biomass energy need land and water (UNEP, 2011*a*); they are directly dependent on the continuous delivery of supporting and regulating ecosystem services such as nutrients for the soil, pollination and water regulation. Healthy ecosystems are in turn essential for meeting the energy needs of poor people (e.g. in the case of fuelwood, the environmental water requirements of forest systems must be met and the erosion of savannah-type ecosystems prevented).

It is difficult to assess the water consumption of bioenergy in general, as opposed to specific biofuels. Livestock, for instance, is an important asset for traction power and transport (a form of bioenergy), meat and milk production, manure (often used as fuel), leather and horns. Livestock water productivity calculations aim to include all benefits per consumed unit of water (Peden et al., 2009). Adding the ecosystems dimension makes the calculations more complicated. If manure is brought back into the ecosystem, it will help nutrient and water cycling, soil formation and, by increasing both fertility and structure of the soil, contribute to the reduction of erosion. However, the same manure can also be used for construction and as fuel for cooking. In the latter case, much of the nutrients are lost to the ecosystem.

Biofuel, as a specific type of bioenergy, is often promoted as an alternative to fossil fuels to reduce GHG emissions (Sections 3.2.2, 6.5). Increasing surface area for biofuels under conventional agriculture leads to sometimes disproportionate increases in the use of land, water (de Fraiture et al., 2008), fertilizers, pesticides, herbicides (GEA, 2012) and other inputs. Hence, unsustainable biofuel production can have significant local implications for the state of water resources (including downstream pollution), land ownership, food security and ecosystems (FAO, 2008). Expansion of biofuel production, and its attendant shift and expansion in agricultural and forestry activity, has raised a number of environmental and social concerns, ranging from potentially increased GHG emissions to labour rights abuses, deforestation (with its own impacts on water flows as well as on firewood provision) and reduced food security (e.g. Fargione et al., 2008). Environmental impacts appear to be less in the case of algal biofuels (Moazami, 2013), though this technology needs to be proven effective beyond the pilot level. New policies and guidelines to better monitor and manage future biofuel production are needed (Groom et al., 2008).

9.2.3 Fossil fuels

The extraction, processing and use of fossil fuels have many impacts on today's ecosystems through water use, pollution and production of GHGs. Oil spills, damaged land, accidents, fires and incidents of air and water pollution are gaining attention in addition to GHG emissions. Oil frontiers are inevitably reaching remote or undeveloped sites, some of which are in environmentally vulnerable or sensitive areas, such as the Iraqi Marshlands of Mesopotamia (Box 9.1). The Ogoniland in Nigeria used to be a wetland high in biodiversity, but oil spills and oil well fires have destroyed the ecosystem and with that, the livelihoods of indigenous communities (UNEP 2011*c*).

BOX 9.1

Impacts of oil extraction in Mesopotamia, Iraq

The Iraqi Marshlands of Mesopotamia comprise the largest wetland ecosystem in West Eurasia. As the ultimate destination for the Tigris and Euphrates waters flowing in the arid region, the Marshlands are vulnerable to hydrological, social, political, economic and environmental events upstream. The Marshlands, which supported rich biodiversity, traditional indigenous lifestyles, and unique natural and cultural landscapes, had been almost destroyed by the time the Iraqi regime collapsed in 2003 because of over-exploitation, a lack of coordinated management and political ill will. Although the new Iraqi government and the international community have made restoration and conservation efforts since 2003, exploitation of supergiant oil reserves near and within the Marshland areas could undo any progress. Water needs for oil extraction will place extra pressure on scarce freshwater resources in the Marshlands and thus threaten many aquatic ecosystem services. Enhanced oil recovery (EOR) requires water injection and water steam to displace and move oil to nearby wells through enhanced recovery wells. Normally, 30% of the oil in a reservoir can be extracted (known as the recovery factor), but EOR increases this and maintains the production rate over a longer period. The oil companies operating in the area would demand approximately one billion m^3 using the least water-consumptive EOR method when oil production is increased to 12 million barrels (1.4 million m^3) per day.

Source: UNEP, from UNEP (2007) and UN (2010).

Water quality can be degraded at every step of the fuel cycle (Allen et al., 2012) in fossil fuel production and use. Extraction, refining and combustion of fossil fuels can pollute water in many ways, through both regular operations and accidental releases. Approximately 15–18 billion m^3 per year freshwater resources are contaminated by fossil fuel production, with significant implications for ecosystems and the communities that depend on the water for drinking or to support their livelihoods. At the global level, the single greatest water impact generated by fossil fuels comes from their combustion and the subsequent climate change, which will have major, long-term impacts on water availability and quality across the planet (Allen et al., 2012).

Hydraulic fracturing uses large amounts of water to extract oil or natural gas from deep rocks (Section 3.2.1). The risk of significant effects due to water abstraction could be high where there are multiple installations. Hydraulic fracturing has recently come under international scrutiny due to its potential environmental impacts. Several studies point out risks to surface water and groundwater contamination, freshwater depletion, biodiversity impacts, land-take, air pollution, noise pollution and seismicity (EC, 2012*b*; US EPA, 2013). Risks include discharges into surface waters, disposal into underground injection wells, spills or faulty construction, explosions from pipeline construction, water contamination with toxic substances (leading to long term-health impacts), and soil and air pollution (Peduzzi, 2012; IEA, 2012*d*).

9.2.4 Thermal power plants

Many thermal power plants use water from nearby rivers or lakes for various processes, especially cooling. Cooling water intake structures can have adverse effects on aquatic fauna, while water released back into water bodies is usually very warm and sterile, disrupting local aquatic ecosystems and potentially altering local habitats and species (Teixeira et al., 2009; Yi-Li et al., 2009). Water in most fossil fuel power plants is also used in other processes, such as flue gas desulfurization, ash handling, coal washing and dust removal. These add pollutants to the water streams, which can have negative impacts on the ecosystem. Moreover, air emissions from thermal power plants' fuel combustion can contain mercury, sulphur and nitrogen oxides, among other chemicals, which may settle and impact water quality and aquatic ecosystems downstream.

9.3 An ecosystems approach to the water–energy nexus

Expansions of all types of energy generation should be planned with an ecosystem perspective (Hoff, 2011). While formal EIAs can quantify the effects that energy generation and water use have on the environment, IWRM can make an ecosystem approach operational in the context of green growth. IWRM encompasses systematic basin hydropower planning, strategic basin water allocation and environmental flows assessment. These all necessitate valuation and use of natural infrastructure. Tools that further support the application of an ecosystems approach include payments for environmental services (PES), remediation through sustainable dam management and strategic basin water investment. Some tools that are most relevant for water management as an entry to the nexus are highlighted below.

9.3.1 Valuing natural infrastructure

Nature can provide critical infrastructure functions for energy provision – in many cases this natural or 'green' infrastructure can complement, augment or replace the services provided by traditional engineered infrastructure (Krchnak et al., 2011). Mixed infrastructure in river basins may result in cost-effectiveness, risk management and sustainable development that are closer to optimal. Improved water resources and natural infrastructure in the form of healthy ecosystems can reinforce each other and generate benefits in the water–energy–food nexus (Hoff, 2011). Ongoing degradation of water and land resources in river basins threatens energy provision. It could be reversed through protection and restoration initiatives, re-establishing natural capacities that support protection against increased climate variability and extreme events (Bergkamp et al., 2003). Some examples of natural infrastructure are described below.

- Wetlands deliver a range of ecosystem services (Krchnak et al., 2011), including regulation of water flows. However, headwater wetlands may actually increase flood flows and decrease low flows (McCartney et al., 2013). Wise use of wetlands is essential for maintaining an infrastructure that can help meet a wide range of policy objectives, including the provision of energy (Box 16.5).

- Healthy floodplains reduce downstream flood peaks by giving rivers the space they need to dissipate peak flows (McCartney et al., 2013; V&W, 2006).

Floodplains are also widely used as grazing grounds, feeding animals that subsequently provide draught power and manure for fuel, and fertile floodplains can be used for biofuel production.

- Coastal wetlands, mangroves, barrier reefs and islands protect inland areas against erosion and storm damage and also attenuate tidal and storm surges, as witnessed in the Asian tsunami of 2004, where damage from coastal inundation was reduced where mangroves were intact (UNEP-WCMC, 2006). Mangrove forests can, if exploited wisely, serve as sustainable providers of firewood and protect critical energy and transport infrastructure (Chong, 2006; Macintosh and Ashton, 2002).

Analytical tools can be used to quantify the services provided by ecosystems and estimate their economic value (TEEB, 2010). An ecosystems approach increases understanding of the interlinkages between water and energy and provides support to decision-making processes, which is fundamental to charting a course to a green economy (UNEP, 2011*b*, pt 1, ch. 'Water'). Economic valuations of the infrastructure benefits of ecosystem services can include market prices for products (e.g. wetland fisheries), the cost of replacing ecosystems through engineering (e.g. water filtration) or the costs of damage avoided (e.g. flood attenuation) (Emerton and Bos, 2004). In some cases, natural infrastructure can be integrated within financing for engineered infrastructure. In many cases, natural ecosystems can provide ecosystem services at a lower price or with higher economic returns than hard engineered approaches, as in the case of wetland restoration (Russi et al., 2013).

9.3.2 Payments for ecosystem services

The approach of payments for ecosystem (or environmental) services (PES) has often focused on supporting watershed protection and water quality enhancements that help water supply by regulating flows (Wunder et al., 2008). It has been suggested that farmers should receive payments or 'green water credits' from downstream water users for good management practices that support and regulate ecosystem services, thereby conserving water and increasing both water availability and quality for downstream users (ISRIC, 2007). Environmental service fees encourage individuals and businesses to internalize the value of ecosystem services. These fees have been established in a number of places around the world, particularly in Latin America (Smith et al., 2006). For example, in the Sarapiqui watershed in Costa Rica, a hydropower company pays US$48/ha per year to upstream landowners for forest management and restoration. The payment is based on the costs of reservoir dredging that the company avoids and the operational benefits of more reliable stream flow that can be used for hydropower (Hanson et al., 2008).

The success of PES schemes depends to a large extent on access to a secure source of funding. This is the case when schemes are operated on the basis of a mutual agreement on the specific ecosystem services required and a price agreeable to the providers and the users. As most government-financed schemes depend on general revenues, typically cover large areas, and are subject to political risks, these are likely to be less efficient and less sustainable (Pagiola and Platais, 2007; Wunder et al., 2008).

__Ongoing degradation__ of water and land resources in river basins threatens energy provision. It could be reversed through protection and restoration initiatives.

BOX 9.2

Sustainable dam management for fish and hydropower

'On Maine's Penobscot River (USA) abundant fisheries were the cultural foundation for the Penobscot Indian Nation and the economic driver of the local economy. A series of hydropower dams built over the past century contributed to the decline of the river's overall health, blocking access for salmon and other species. The power company, the Penobscot Indian Nation, environmental groups and numerous state and federal agencies and riverside communities joined forces to restore more than 1,000 miles [1,600 km] of river habitat without diminishing hydropower generation in the basin ... [by] removing two dams in the lower river, installing a state-of-the-art fish bypass to a third dam further upstream and increasing energy production at dams elsewhere in the basin where impacts on fish are low.'

Source: UNEP, from Krchnak et al. (2011, p. 7).

9.3.3 Strategic river basin development

A common vision for economic development and environmental sustainability, achieved through approaches from consensus-building among stakeholders to integrated planning, can be the basis for strategic investments in multiple sectors (Krchnak et al., 2011). In response to frequent severe flooding in the Magdalena River basin, the Government of Colombia has given central importance to an ecosystem-based approach to regulating planning and development to make sure that future economic activity in the basin – especially hydropower and agriculture – is regulated to take into account river dynamics, flows, other water uses and adaptation to climate change. This key river basin produces 86% of the country's GDP, 75% of its agricultural production and more than 90% of its lucrative coffee crop, as well as 70% of its hydropower and 90% of its thermal power. With its combination of natural and man-made infrastructure, the Magdalena provides a vast transportation network of interconnecting rivers, channels and canals that link producers to global markets (Krchnak et al., 2011). Strategic river basin planning can help build synergies between water, energy and environmental concerns (Pegram et al., 2013).

9.3.4 Sustainable dam management

Throughout the various processes of energy provision, measures can be taken to reduce the impacts of water–energy interactions on ecosystems. Many methods have been developed to address the sustainability of hydropower, such as the Rapid Basin-wide Hydropower Sustainability Assessment Tool (RSAT)[22] and the Hydropower Sustainability Assessment Protocol (HSAP).[23] The need for new dams could be reduced by retrofitting existing dams with power generation installations and other ways of turning them into multi-purpose structures, as well as increasing operational efficiency by better integration of natural infrastructure in catchments. The negative impacts of current dams on fish and other aquatic life can be reduced by applying decision models that include environmental flows and other such considerations in the management of hydropower dams (McCartney, 2007). Better design elements such as modified intake screens, acoustic deterrent systems, barrier nets and variable speed pumps can reduce the negative impacts substantially. Sustainable dam management goes a step further and is based on designing new and regulating existing infrastructure to address overall system health (Box 9.2).

[**See Chapter 26** (Volume 2) for the case study 'The Four Major Rivers Restoration Project as a part of the National Green Growth Strategy in Republic of Korea'.]

9.3.5 Conservation and remediation

Actions to avoid land degradation contribute to savings in water and energy consumption by, for example, increasing groundwater recharge and soil water storage or reducing the use of energy intensive fertilizer (Hoff, 2011). In this way, water conservation can also help reduce GHG emissions (Maas, 2009). Managing for multiple uses below the basin level can also reduce pressure on water resources by increasing water productivity, for example when irrigation canals, downstream of a hydropower dam, are used for aquaculture, or when water from laundry basins is diverted to vegetable plots (Van Koppen et al., 2009). Water can yield more ecosystem services when it is managed not for a single purpose such as crop production but as part of a multifunctional landscape of agro-ecosystems, thus also benefitting biodiversity, groundwater recharge and erosion control (Keys et al., 2012; Boelee et al., 2011).

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[22] For more information, see http://www.mrcmekong.org/news-and-events/news/innovative-tool-for-mekong-basin-wide-sustainable-hydropower-assessment-launched/

[23] For more information, see http://www.hydrosustainability.org/

PART 3

REGIONAL ASPECTS

CHAPTERS

The regional chapters of Part 3 cover Europe and North America, Asia and the Pacific, the Arab region, Latin America and the Caribbean, and Africa. The delineation of the five regions follows the regional division of the United Nations regional economic commissions (UNECA, UNECE, UNECLAC, UNESCAP and UNESCWA; maps of the Member States can be found in the fourth edition of the WWDR [WWAP, 2012, ch. 7]). For the Arab region and Africa chapters, it was decided (in agreement with UNECA and UNESCWA) that all the Arab countries would be reported on in the Arab region chapter rather than having some of them included in the Africa chapter.

CHAPTER 10

Europe and North America

UNECE

Annukka Lipponen

The UNECE region, extending from North America, through Europe to Central Asia, is highly diverse in terms of water resources availability, energy sources and energy mix, and socio-economic development. While the challenges at the interface of water and energy differ, a few major issues emerge across the region.

Renewed interest in hydropower may allow capacity expansion of other renewable energy sources, reduce carbon dioxide emissions and, in some cases, better cope with the predicted increase in variability of flows. However, there are also related concerns. In many areas, hydropower generation is in conflict with other water uses, notably irrigated agriculture. Hydropower is one of the main drivers of hydromorphological alteration, loss of connectivity and change in the flow of water and sediment. In the EU in particular, numerous projects are under way to address the negative impacts of hydromorphological changes, such as restoration of habitats and river continuity (e.g. ICPR, 2010).

Because of concerns related to the safety of nuclear power plants, many European countries (e.g. Germany, Sweden, Switzerland) are presently considering reducing or even phasing out nuclear power generation.

Freshwater supplies are increasingly augmented by highly energy intensive methods (e.g. desalination), especially where water scarcity prevails. Limited policy coherence may aggravate the situation because of the complex interlinkages between water and energy issues. Informing policy formulation requires suitable data and information (OECD, 2010*a*). Where transboundary impacts may occur, consistency of data across borders is necessary for an accurate and holistic view. A better understanding of inter-sectoral impacts, trade-offs and benefits is needed to inform dialogue.

The recent call for a coordinated approach to better manage energy and water trade-offs in the USA resonates with the rest of the UNECE region: improved energy and water planning will require better coordination among national/federal agencies and other stakeholders as well as consideration of impacts to both resources (US GAO, 2013). Uncertainties in climate change, population growth and demographic shifts are expected to exacerbate the challenges associated with managing both the supply and demand of water and energy, and need to be accounted for when developing national policies (Howells et al., 2013; US GAO, 2013).

10.1 Hydropower

The region's hydropower sector is mature, and developments focus on modernizing and refurbishing existing plants as well as expanding pumped storage capability (Figure 10.1). In Europe and in North America, some 65% and 61%, respectively, of hydropower generation potential is estimated to have been already developed, according to the IEA (IEA-EC, n.d.). Some countries are still developing new capacity. Additional pumped storage facilities to balance supply with demand are under construction in the European Economic Area[24] and the USA. In 2008, hydropower generated 16% of Europe's electricity; there are currently more than 7,000 large dams and a number of large reservoirs in Europe (EEA, 2009). Hydropower has been a particularly dominant aspect of industrial development in the northern and Alpine countries.

The renaissance in expanding pumped storage capacity in Europe (Figure 10.1) is driven by the increasing share of intermittent electricity sources, such as wind and solar, in the energy mix, which stored electricity helps to integrate. The increasing development of renewable energy sources is spurred by the Renewable Energy Directive,[25] which lays down legally binding targets; notably, a 20% share of renewable energy in the EU by 2020. There are significant new development projects in the pipeline in South-Eastern Europe, Eastern Europe, the Caucasus and Central Asia.

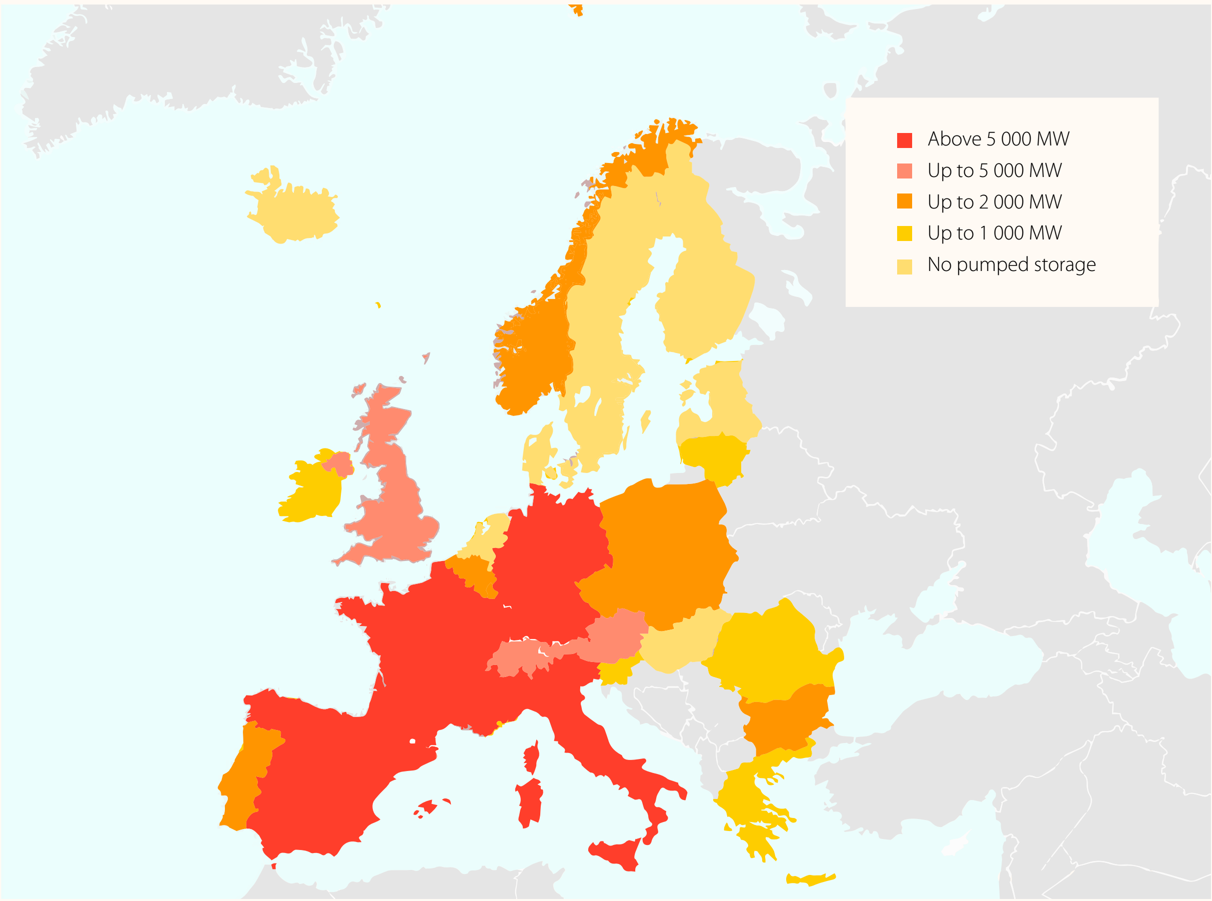
High investment requirements and environmental impacts of large-scale projects have increased interest in the construction of small-scale hydropower installations, especially in remote rural areas. But there are some barriers to this approach. For example, in Albania, where most energy is produced by hydropower, small individual projects are not necessarily well structured (reducing their appeal to investors), equity capital is lacking, and capacity and public awareness are low (UNECE, 2009).

10.2 Conflicts over water use between energy and other sectors, and across borders

In parts of the UNECE region, conflicts exist over water for irrigated agriculture (over the growing season) and for hydropower generation (particularly in winter). For transboundary rivers, it may be particularly difficult for the multiple countries affected to reconcile their different uses over different time periods regarding flow regulation,

10.1 FIGURE

Pumped storage capacity in Europe (data from the beginning of 2011)



Source: ecoprog, The European Market for Pumped Storage Power Plants 2011/2012.

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[24] The European Economic Area includes the EU, Iceland, Norway and Liechtenstein.

[25] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.

although there are examples of joint management of regulation infrastructure. Hydropower development projects are planned in South-Eastern Europe and in the Caucasus, many of them on transboundary rivers; for example, the Sava, Bosna, Morača, Vjosa and Devoll in South-Eastern Europe (ECA-Watch/Euronatur, 2012) and the upper reaches of the Aras and the Kura in Turkey as well as the Çoruh. In Central Asia the conflict between sectoral water uses is particularly prominent. The construction of a number of new dams, mainly for hydropower but also for irrigation purposes, was initiated in the 2000s, with ongoing and planned projects at least on the Naryn, Tejen and Vakhsh rivers. Some of these are heavily disputed between the riparian countries due to concerns about transboundary effects. Because of facility ageing and inadequate maintenance, concern has grown in recent years over the safety of more than 100 large dams and other control facilities in Central Asia, located mostly on transboundary rivers (UNECE, 2011*a*).

Responses to intersectoral conflicts over water use can include a more commercial approach to structuring and regulating energy markets (World Bank 2010*c*); a wider view of the benefits of cooperation (going beyond allocating volumes of water); and a strengthened institutional basis for project development and management (UNECE, 2011*a*; Granit et al., 2012).[26] Such responses also relate to the water–energy–food nexus in a broad sense. Shortcomings in energy infrastructure and trade as well as problems in transboundary and broader cooperation in Central Asia do not presently allow for resolution of the conflict between water use for hydropower and irrigated agriculture. Environmental impact assessments of planned infrastructure projects with potential significant adverse transboundary effects on shared waters should be carried out more systematically.[27]

__Improved energy and water planning__ will require better coordination among national/ federal agencies and other stakeholders as well as consideration of impacts to both resources

10.1 BOX

Complex impacts of modernizing irrigation and the role of energy

Irrigated agriculture in Spain went through a rapid transformation from 2002 to 2009, and currently accounts for 40% of the country's total water-related electricity demand. The use of drip irrigation systems, involving replacement of gravity irrigation systems, increased by 40% between 2002 and 2008. The net electricity consumed in irrigation increased by 10% per volume unit during the same period. However, from 2006 to 2008 the price for energy increased by 30% to 70% and energy consumption dropped, illustrating the complex dynamics of the situation. Modernizing irrigation systems requires major investment and there is a risk that water consumption will increase and returns will decrease. Consequently, a thorough assessment of possible increases in energy consumption must be made: how they can be met, at what cost and with what impacts on the environment.

Source: UNECE, from Hardy et al. (2012).

10.3 Coping with water scarcity

Inefficient use of water leads to higher energy use, with extra financial and environmental costs. However, even the application of more efficient irrigation methods may introduce higher energy requirements (Box 10.1; Chapter 6).

Southern European countries and parts of the USA are increasingly using desalination to meet their water needs, with significant implications on energy consumption.

10.4 Climate change outlook and effects of water scarcity on thermoelectric power plants

Thermoelectric power plants produce 91% of total electricity in the USA and 78% in Europe. Cooling water scarcity during recent warm, dry summers led several thermal (nuclear and fossil-fuelled) power plants in Europe and the south-eastern USA to reduce production. Climate change is expected to aggravate the situation in areas where lower summer flows and higher river water

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[26] The UNECE's assessment of water-food-energy-ecosystems in selected transboundary river basins (2013–2015) will provide analysis as well as further the identification of and dialogue on opportunities for synergy and cooperation.

[27] Guidance on such assessment is provided by UNECE instruments: the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki Convention) and the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention).

temperatures are anticipated (van Vliet et al., 2012). An increase in and spread of water scarcity and stress is predicted to affect about half the river basins in the EU by 2030 (EC, 2012*c*). Countries that depend on imported energy may also be exposed to effects of change and variation in climatic conditions (e.g. the Netherlands; Rübbelke and Vögele, 2011). In Western Europe and the USA, roughly 50% of water is abstracted for energy production as cooling water, and the majority of this is discharged to water bodies at a higher temperature (EEA, 2009).

10.5 Extraction of natural gas and oil from unconventional sources

The USA has experienced a tremendous expansion of natural gas extraction from unconventional sources[28] with hydraulic fracturing ('fracking'), due to technical developments that have made the extraction more economically viable (IEA, 2012*d*; Cooley and Donnelly, 2012). Between 2005 and 2010, shale gas production in the USA grew more than 45% per year. Parts of the UNECE region also have potential unconventional natural gas resources, some of which have been explored, notably in France, Germany, Poland, Sweden and the United Kingdom (UK). Increasing indigenous energy production and diversifying energy sources are behind the appeal of unconventional natural gas resources, but concerns about the impacts of hydraulic fracturing on the environment and on water resources specifically (Section 3.2.1) have raised public opposition in the above-mentioned countries (IEA, 2012*d*).

Canada faces water management challenges related to exploiting large, low-quality unconventional petroleum reserves in oil (tar) sands (e.g. University of Toronto/University of Alberta, 2007). Medium- and long-term impacts remain unclear, and recent independent reports emphasize the need for improved monitoring to ensure the sustained functioning of aquatic ecosystems and public health in human settlements downstream (CESD, 2010; Royal Society of Canada, 2010).

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[28] Definitions of the categories are available from IEA (2012*d*, p. 18).

CHAPTER 11

Asia and the Pacific

UNESCAP

Nowhere is the critical inter-relationship between water and energy more evident than in the Asia-Pacific region, considering its huge population and size. Home to 61% of the world's people and with its population expected to reach five billion by 2050 (UNESCAP, 2011), the region's rapid population growth is accompanied by a burgeoning economic presence. The Asian Development Bank (ADB) estimates that developing Asia has an average 6% annual GDP growth, and forecasts a massive rise in energy consumption in the Asia-Pacific region: from barely one-third of global consumption to 51–56% by 2035 (ADB, 2013).[29] The ability to address issues of water availability and distribution will play an important role in the region's capacity to grow and develop. Some areas of the region have water in abundance, with current withdrawals in at least 11 UNESCAP Member States below 10% of total actual renewable freshwater resources (TARWR). Asia's per capita freshwater availability nonetheless remains half of the global average (FAO, 2011*e*), and almost 380 million people do not have access to safe drinking water (UNESCAP, 2013). Compounding chronic uncertainties in water availability and quality is the fact that this region is the most vulnerable to climate change impacts in the form of extreme weather-related disasters (UNESCAP, 2013).

Asia is also where 46% of the global primary energy is produced (UNESCAP, 2011). Coal is the most prevalent energy product within the region, with China and India together extracting more than half of the world's total output (World Coal Association, 2011). There is also a growing market for renewable sources such as biofuel, with China, India, Malaysia, the Philippines and Thailand among the leading regional producers (UNESCAP, 2012). Both coal and biofuel require vast amounts of freshwater (Chapter 3), and some areas within the region are already deemed water-scarce (Figure 1.1).

Potential sites for hydropower development exist in upstream countries of South-East Asia and South Asia (Figure 3.11), and the majority of added capacity on a global scale in 2011 occurred in Asia (REN21, 2012). But concern over the potential adverse effects of hydropower raises other issues, for example in the lower Mekong delta, where 45 million people are reliant on the river system for their livelihoods and sustenance (ADB, 2013). Twelve dams are set for construction in 2011–2015, and altered river ecology and disrupted fisheries are critical issues (Orr et al., 2012).

Whether considering water use in energy production or energy requirements for water service provision, concerns over water availability and energy demand in the Asia-Pacific region are compounded by environmental considerations. The application of multi-scale integrated analyses could be useful in evaluating trade-offs based on societal and ecosystem functioning and requirements. For example, FAO and LIPHE4 (a non-profit scientific association) are studying current trends in future options for balancing food production and groundwater pumping, given the potential reduction of subsidies for electricity use in agriculture, against local sustainability criteria in Punjab, India (FAO/LIPHE4, 2013).

11.1 Hydropower

The potential for hydropower generation in countries such as Bhutan, Lao People's Democratic Republic and Nepal, and in countries with large populations such as China, India and Thailand presents an economic opportunity, particularly as cross-border power interconnections increase (e.g. ASEAN Power Grid, SAARC Market for Electricity, proposed Asian Energy Highway).

Countries with short, swift rivers can benefit from small hydropower installations (100 kW to 30 MW capacity), particularly if these are integrated with land use plans and overall economic development. Such countries include the Democratic People's Republic of Korea, Indonesia, Malaysia and the Republic of Korea, as well as some of the small island developing states (SIDS) in the Indian Ocean, Pacific Ocean and South China Sea. Installations may also be advantageous on certain tributaries of big rivers, particularly if these projects extend benefits to rural communities and the alteration of flow patterns does not have significant downstream effects. Small-scale projects

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[29] ADB's Asia-Pacific region excludes the Russian Federation.

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in Tajikistan, for example, are helping rural communities such as in Bozorboi Burunov Jamoat gain access to social services and secure a reliable heat source in the cold winter months (UNDP, 2011).

Existing and potential hotspots in Asian transboundary river basins develop where issues and challenges for both energy and water have political and socio-economic implications at local and basin levels. Areas of conflict include the Aral Sea, Ganges-Brahmaputra River, Indus River and Mekong River basins. The Mekong River basin in South-East Asia spans Cambodia, China, Lao People's Democratic Republic, Myanmar, Thailand and Viet Nam. Although a 2011 Environmental Impact Assessment of the Mekong River Commission indicated that the 11 proposed mainstream dam projects could reduce the GHG emissions of the regional power sector by 50 million tonnes by 2030, severe ecological consequences such as disruption of fish migration, erosion and biodiversity loss are anticipated (MRC, 2011). In the Ganges-Brahmaputra River basin (Bangladesh, Bhutan, China, India and Nepal), the Zangmu Dam in Tibet, a run-of-the-river facility slated for completion in 2015, as well as the recent approval of three more Brahmaputra dams as part of China's Twelfth Five Year Plan, are raising concerns over downstream effects in India and Bangladesh.

11.2 Coal

While already heavily reliant on coal, Asia's demand for this primary energy source is projected to increase by 47% in coming years, which will account for 119% of the global total increase in demand (IEA, 2010). The location of water intensive coal mining in water-scarce areas is becoming increasingly controversial in many parts of Asia; for example, in India, where 16% of the world's population has access to only 4% of its water resources (InfraInsights, 2013). Given that coal contributes to more than half of India's primary commercial energy, and is likely to do so for the next few decades, concern is mounting over falling water tables in areas already struggling to meet water demand (Sreenivas and Bhosale, 2013). Expansion plans for coal power plants in China and India could be unachievable due to water scarcity issues (Adelman, 2012).

Continued coal production and growing energy demand in the Asia-Pacific region is closely aligned with high population and economic growth. This expansion can offset burgeoning investments in renewable or cleaner energy. China, although one of the largest producers and users of coal in the world, was also the dominant country for investments in renewable energy in 2012, with commitments rising to US$67 billion – a 22% increase from 2011 (Frankfurt School-UNEP Centre/BNEF, 2013). Other nations have set ambitious goals in energy system transitions. As South-East Asia's biggest economy, Indonesia intends to increase renewable energy usage to 17% by 2025, a shift aided by co-financing mechanisms targeted at developing geothermal and biomass capacities (Climate Investment Funds, 2013). At the same time, Indonesia overtook Australia as the world's largest exporter of coal in 2011 (ADB, 2013), and its domestic consumption (under 23 million tonnes less than a decade ago) has been projected to reach 72 million tonnes by 2020 (Indrayuda, 2005).

Serious concerns about water quality degradation as an effect of coal mining in many parts of the region are being raised. Without careful regulation, contamination from acid mine drainage can seriously compromise ground and surface water resources. A recent water quality survey of the Grose River in Australia – an area with a history of more than a century of mining operations in an otherwise pristine region of the Greater Blue Mountains – detected a considerable level of water contamination, a result of leaching from the disused mines (Wright et al., 2011).

11.3 Biofuels

Asia is increasingly recognized for its potential to develop into a significant market for and exporter of biofuels (Zhou et al., 2009). Indonesia and Malaysia are the top two global producers of palm oil (InfraInsights, 2013), and China is the third largest producer of biofuels overall in the world (European Biofuels Technology Platform, 2009). India, the Philippines and Thailand are major new contributors to the biofuel industry (PR Newswire, 2009). A recent study from the Global Biofuels Center points to tremendous growth in overall ethanol production in the Asia-Pacific region, which could amount to as much as 20% of total global production by 2015 (Adelman, 2012).

There is a hope that the evolving biofuel industry will help job growth in several developing nations. Indonesia, currently producing almost 45% of the world's total palm oil with around 8% of land designated for this purpose (Climate Investment Funds, 2013), has targeted biofuel development as a way to increase the income of on- and off-farm workers (Komarudin et al., 2010). In China, growing interest and investment in advanced biofuel technology could potentially lead to the creation of 2.9 million jobs by 2030 (Bloomberg, 2012).

Although it provides a cleaner energy source and is a potentially strong economic driver, the biofuel industry has large water requirements that could exceed capacity in some regions (Section 3.2.2). China, already facing a pressing shortage of water and shrinking supply of arable land, has a goal of producing 12 million metric tonnes of biodiesel by 2020 (Timilsina and Shrestha, 2010) – a target that requires an amount of water approximately equivalent to the annual discharge of the Yellow River (ADB, 2013). Solutions in impact mitigation could lie in biofuel production from agricultural by-products or waste, or investments in algal fuel production as its cost efficiency improves. Research and development in algal fuel in many parts of the Asia-Pacific region, such as Japan and Korea, is resulting in its gaining ground as a sustainable alternative to biofuel and biomaterial production.

CHAPTER 12

The Arab region

UNESCWA

Carol Chouchani Cherfane and Sung Eun Kim

Although Arab countries form a homogeneous geopolitical region that is among the water poorest of the world (WWAP, 2012, ch. 33), countries can still be clustered according to the severity of their water scarcity and their energy endowments. Member countries of the Gulf Cooperation Council (GCC) are among the water poorest in the region, but thanks to their prodigious oil and gas reserves, they have the economic capacity to overcome water scarcity through desalination and to consume water at rates that are among the highest in the world. In contrast, four of the region's six least-developed countries (the exceptions being Djibouti and Yemen) have an annual per capita water share that exceeds the water poverty level of 1,000 m^3, yet they are unable to mobilize economic growth; oil production in Sudan and Yemen has not helped to improve water use efficiency or water security in either country. With the exception of Iraq and Lebanon, the low to middle income countries in the region have an annual per capita share of renewable water resources that falls below the water poverty line (UNESCWA, 2013*a*) and are struggling to achieve energy security; many are seeking to reorient their energy mix towards renewable energy sources to meet growing demand for water and energy services.

12.1 Increasing knowledge and awareness-raising for policy coherence

The Arab region is seeking to improve understanding and awareness of the water–energy nexus at the policy and operational levels. While IWRM has been promoted in the region for more than a decade, limited understanding of the interdependencies affecting the management of water and energy resources has stymied coordination between the water and energy policy-makers, even when these sectors are managed within the same ministry.

Energy requirements for surface and ground water extraction are not regularly monitored in the region, while energy demand for desalination processes continues to increase. Although energy requirements for water supply services differ depending on the type of pump used, the efficiency of a water supply system and the topographic conditions, there is a need to improve the monitoring and management of energy resources used in the production and distribution of water. Approximately 0.36 kWh is needed to lift 1 m^3 water a vertical distance of 100 m, and 0.04 kWh is needed for pumping 1 m^3 water a horizontal transfer distance of 100 km (UNESCWA, 2009*b*). This is particularly significant when considering the energy costs associated with the distribution of water desalinated along the coastline to inland communities in the Arabian Gulf and southern Mediterranean countries. The energy requirements for producing and distributing desalinated water would be prohibitive for the water-scarce city of Sana'a, Yemen, which lies 2,200 m above sea level, and thus desalination cannot be considered a sustainable solution for what may be the first capital city in the region to run out of water (UNESCWA, 2009*b*).

Limited coordination between the water, energy, electricity and agriculture sectors leads to conflicting policies and development objectives. For example, energy costs for groundwater pumping at increasingly greater depths are increasing production costs and reducing revenues for small-scale farmers in Jordan, Lebanon and Palestine. Water operators in Jordan, Lebanon and Yemen complain of high energy costs and the rationing of

BOX 12.1

Intermittent supply and unaccounted-for water

'The intermittent supply of water through distribution networks can increase the volume of unaccounted-for water that is lost through the network as water pressure variability increases the stress on pipes and joints, resulting in cracks in the network and associated leaks. While intermittency is sometimes caused by water rationing due to water scarcity, limited access to reliable and adequate energy supplies by water operators due to electricity rationing or high energy costs has also constrained their ability to provide water services on a continuous basis throughout the network. This condition is commonly experienced in Jordan, Lebanon, Palestine and Yemen.'

Source: UNESCWA (2011a, p. 14).

electricity services, which has forced some water utilities to provide intermittent water services to urban and rural communities (UNESCWA, 2009*a*). Civil crises and unrest in the region have also affected delivery of basic services, while energy shortages affect the ability to supply water.

Unaccounted-for water in Arab countries is estimated to vary between 15% and 60%, whereas the best practice rate ranges from less than 10% for new systems to 25% for older systems (World Bank, 2009). The high percentage of water losses in Arab countries is coupled with high energy losses, which further increases the cost of service provision (Box 12.1). This challenge is all the more true when water is sourced from desalination plants.

12.2 Informing technology choice and renewable energy options

The Arab region is situated in a sunbelt that receives about 300 sunny days per year. The annual direct solar irradiation in all Arab countries exceeds the defined threshold for economic potential for concentrating solar power (UNESCWA, 2010). This has prompted research and development and investment in solar desalination in the Mashreq and Maghreb (Box 12.2) (see Chapter 20 [Volume 2] for the case study 'Desalination in Gulf Cooperation Council countries').

Energy recovered from wastewater treatment plants (Section 5.2.4) is almost non-existent in the Arab region, even though the best-performing wastewater treatment plants can produce more energy than is needed for treatment (WERF, 2011). This is partially because most wastewater treatment plants in the Arab region are based on aerobic treatment systems that are commonly found in Europe, the USA and cooler climates. Anaerobic technologies for wastewater treatment are more suitable for the warmer Arab region and are more energy efficient because they do not require energy for aeration to maintain the dissolved oxygen levels needed for aerobic bacterial growth. In addition, anaerobic processes can produce biogas, which can fuel the treatment facility, and digested sludge cake, which can be processed into safe, high quality agricultural fertilizers.[30] Investments in sanitation thus present opportunities for biogas production in some Arab countries, based on regional specificities (Box 16.3).

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[30] Aerobic wastewater treatment uses the biological processes of oxidizing and decomposing organic matter by microorganisms in the presence of oxygen. Anaerobic treatment is a bacterial process that is carried out in the absence of oxygen. Anaerobic treatment is much more sensitive to low temperatures than is aerobic treatment. Anaerobic treatment processes are performed in temperatures ranging from 25°C to 35°C (Metcalf and Eddy, 2003). This is important to consider when pursuing green investments or appropriate technology transfer arrangements in the warmer climates found in the Arab region.

BOX 12.2

Solar desalination in the Mashreq and Maghreb

Solar energy investments are increasing in the Arab region for desalination and the creation of green industries. The King Abdul-Aziz City for Science and Technology in Saudi Arabia launched a national initiative for water desalination using nanotechnology to produce solar energy and water desalination membranes at low cost. The first phase of the initiative was achieved by building a solar energy-powered water desalination plant in Khafji with a production capacity of 30,000 m^3 per day (KACST, 2012). Egypt constructed its first concentrating solar power system generating 140 MW solar power; another concentrating solar power project of 100 MW is in preparation (NREA, 2012). In the United Arab Emirates, a solar photovoltaic power plant was inaugurated in Masdar City in June 2009 and produces about 17,500 MWh of clean electricity annually. However, the site faces challenges in supplying the freshwater necessary to remove dust and sand that accumulates on the solar panels. Nevertheless, a 100 MW concentrated solar power project remains in preparation nearby; it will extend over an area of 2.5 km^2 and have a solar field of 768 parabolic trough collectors to generate clean, renewable electricity (Masdar, n.d.). During the UNFCCC 18th Conference of the Parties (COP-18) held in Doha in December 2012, the Government of Qatar reaffirmed its goal to meet 80% of its freshwater needs through a 1,800 MW solar-powered water desalination plant. Solar and wind energy investments are also strongly promoted in Egypt, Morocco and Tunisia. In Morocco, the current energy strategy plans a very quick development of the renewable energy sector and aims to satisfy 42% of the national energy needs though renewable energy production by 2020.

Source: UNESCWA.

***With the exception of Iraq and Lebanon**, the low to middle income countries in the region have an annual per capita share of renewable water resources that falls below the water poverty line and are struggling to achieve energy security; many are seeking to reorient their energy mix towards renewable energy sources to meet growing demand for water and energy services*

12.3 Addressing climate change and natural disasters

Climate change is directly and indirectly impacting production and consumption of water and energy resources in the Arab region. Rising temperatures are increasing evapotranspiration rates and water demand in an already thirsty agriculture sector. As temperatures rise, so does the need for cooling, which requires water and electricity for industry and housing units. Energy efficiency in the building sector is being promoted in the Gulf and the Mashreq, as are closed-loop cooling systems in industrial and commercial facilities. Sea level rise associated with climate change presents risks to urban and agricultural development in low-lying coastal areas along the Egyptian delta and across the island state of Bahrain. Real estate investments on artificial islands, desalination plants and offshore oil installations are also being affected by extreme weather events and sea surges that have been felt more prevalently over the past decade along the eastern Arabian Peninsula. Flooding has strained ageing or inadequate stormwater systems, while drought has forced farmers to migrate to cities, increased the price of food and fostered social unrest.

With a view to increasing understanding of the impact of climate change and extreme events on the Arab region associated with the new radiative forcing scenarios developed by the IPCC, the United Nations, the League of Arab States and other international organizations have launched the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR). RICCAR is generating regional climate modelling and hydrological modelling projections and a multi-sectoral vulnerability assessment for the Arab region (UNESCWA, 2011*b*), which will inform further work on the water–energy nexus and climate change adaptation as well as mitigation efforts in the Arab region.

Despite challenges, efforts are being made to improve cross-sectoral coordination and policy coherence across the water and energy domains. Intergovernmental processes have been launched (UNESCWA, 2013*b*) and the need for integrated approaches for achieving sustainable development, including integrated regional approaches for pursuing water security, energy security and food security, have been identified (LAS, 2011).

CHAPTER 13

Latin America and the Caribbean

UNECLAC

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Water and energy inter-relationships in Latin America and the Caribbean are diverse, complex and intense. Current trends suggest that this interdependence will be subject to increased stress in the future mostly because of population growth and urbanization; rising income levels and economic growth; competition for water in river basins with concentrated economic development; and tendencies towards increasing the water intensity of energy production and the energy intensity of water provision for different uses – all this in the context of climate change. There are two principal areas of the water–energy nexus that stand out at the regional scale:

- Water use for hydropower generation
- Energy consumption in the provision of water services

This is not to say that the water–energy nexus in the region is limited to these two issues. There are various other water and energy inter-relationships, but most of them are either specific to particular areas or countries, or not unique to the region. The most important of these other issues are the following:

- The impact of electricity subsidies to farmers on aquifer sustainability (as in Mexico and Argentina) as well as on social equity. The powerful economic incentives created by these subsidies often make it virtually impossible to prevent aquifer deterioration through regulatory instruments alone (Solanes and Jouravlev, 2006). In Mexico, for example, subsidies for electricity used for pumping 'have detrimental impacts on water demand and groundwater management, and mostly accrue to the richest farmers, making this a particularly regressive subsidy' (OECD, 2013*b*).
- An increasing interest in biofuels (Saulino, 2011), although in Brazil – the main producer – ethanol primarily comes from sugar cane, which is rain fed (Scott and Sugg, 2011).
- A slowdown in the expansion of irrigated area accompanied by a shift to more water efficient, and more energy intensive, irrigation methods (as in Chile and Mexico), and its negative impact on aquifer sustainability due to increased consumptive use and reduced return flows.[31]
- The impacts of the use of water for cooling in thermoelectric power plants (Section 3.3.1), including the growth in the nuclear energy industry in Brazil.
- The perspectives of introducing hydraulic fracturing (Section 3.2.1) in the region, as in Argentina and Mexico, and its implications, especially for groundwater quality.

13.1 Water use for hydropower generation

Latin America and the Caribbean has the second largest hydropower technical potential of all regions in the world – about 20% (of which almost 40% is in Brazil) or approximately 700 GW. Less than one-quarter of this is developed (IEA, 2012*b*; OLADE, 2013). The region has experienced an impressive hydropower expansion, including large binational hydropower projects such as Itaipú, Salto Grande and Yacyretá, which are examples of the long tradition of transboundary cooperation in the region, especially since the 1970s. At present the region has almost 160 GW of installed capacity. As a result, hydropower provides some 65% of all electricity generated (even more in Brazil, Colombia, Costa Rica, Paraguay and Venezuela); in comparison, the world average is just 16% (IEA, 2012*b*). Hydropower development slowed

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[31] Improvements in on-farm irrigation efficiency that increase evapotranspiration (e.g. because of application of 'saved' [or salvaged] water to additional crops) 'fail to conserve water on a broader geographic scale when irrigation return flows are an important component of basin-wide hydrology' (Huffaker, 2010, p. 134). Therefore, investing in more efficient irrigation methods but allowing expansion of irrigated area is likely to actually reduce water availability, increase the energy intensity of agriculture and stress water supplies.

> ***Given intense competition** for limited water supplies and the predominant role of hydropower in river basins, conflicts increasingly arise between hydropower and consumptive uses*

down between the late 1990s and the early 2000s as increased private participation resulted in a preference for less capital intensive technologies (thermal power), and also because of heightened public opposition to the environmental and social impacts of large dams.

Since then, in response to rising energy prices, escalating demand and growing concerns about climate change, hydropower development has accelerated again, predominantly in Brazil, which concentrates more than 60% of the new capacity installed in the past decade, followed at a distance by Chile, Paraguay and Mexico (OLADE, 2013). Hydropower projects play a central role in the expansion plans of many countries (IEA, 2012*b*), and are expected to be a major driver of new water demands in the future. At present, the emphasis is not only on large plants, capable of multi-year regulation, but also increasingly on smaller single-purpose reservoirs (the average reservoir capacity of the dams built in the 2000s is only about one-fifth of those commissioned in the 1980s and 1990s [ICOLD, 2013]), run-of-the-river plants, and modification of existing dams to increase their generation capacity. Another concern relates to the vulnerability of hydropower to climate variability. In Brazil, climate change is expected to decrease the overall reliability of hydropower, with negative effects concentrated in the North East and North regions, in terms of both average and firm energy, and positive variations in the South and South East river basins (Margulis and Dubeux, 2011).

Hydroelectric power is usually viewed as a non-consumptive water use, even though it is in part consumptive (reservoir evaporation) and has important impacts on other attributes of streamflows (timing and quality). Given intense competition for limited water supplies and the predominant role of hydropower in river basins, conflicts increasingly arise between hydropower and consumptive uses, as with irrigated agriculture in Brazil and Chile (Dourojeanni and Jouravlev, 1999), and in some cases with other instream uses, like recreation. These conflicts are particularly common where hydropower relies on reservoirs with multi-year storage to allocate streamflow to meet power demand that is often out of phase with the seasonal requirements of other water uses, especially irrigation (Huffaker et al., 1993). In Chile, conflicts emerge between farmers who prefer to store water during winter for use during the summer growing season, while hydropower requires water to be stored during summer to meet high electricity demand in winter (Bauer, 2009). As reservoirs are often located upstream and are controlled by hydropower interests, farmers sometimes find much of their water cut off during the peak of the irrigation season; in some cases, they have had to be compensated by hydropower companies. In many countries, there are concerns about the impact of dam construction and operation on aquatic ecosystems and water quality.

In Chile, the granting of water rights without the requirement of beneficial and effective use created a barrier to entry for competitors in various markets, particularly electricity generation, thus potentially reducing competition and fostering monopolization. As a result of the 2005 Water Code reform which, among other measures, introduced a licence fee for unused water rights, the situation has improved and unused water rights no longer present an impediment to energy sector development (Peña, 2005).

13.2 Energy consumption in the provision of water services

In comparison with other developing regions, Latin America and the Caribbean is well advanced in the provision of water supply and sanitation services: 94% of its population has access to improved water sources and 82% to improved sanitation facilities (WHO/UNICEF, 2013*b*). Rising energy expenditures present challenges for the water industry: energy is often the highest component of operational costs (30–40%) associated with water supply services in the region (Rosas, 2011). The reasons for this situation are manifold:

- Inefficient system design and operation, with little if any attention to energy efficiency

- Bad asset condition and high unaccounted-for water (40% on average [Mejía and Rais, 2011], but up to 75%

in extreme cases [Jouravlev, 2004]), including both physical and commercial losses

- Low level of household metering (as in Argentina, Panama and Paraguay) or artificially low tariffs, resulting in water consumption far above normal levels and in over-dimensioned water production and treatment systems (Ferro and Lentini, 2013; Jouravlev, 2004)

- Heavy reliance on groundwater, which accounts for more than half the water supply in many countries, with increasing pumping costs due to falling water tables in many areas due to inadequate aquifer management

- The need to meet more stringent drinking water and effluent quality standards, but especially to resort to more distant (as in Mexico City and São Paulo), less convenient and more polluted water sources, or even to seawater desalination, particularly in the Caribbean (as in Aruba and Trinidad and Tobago) and arid areas of Brazil, Chile, Mexico and Peru

- Wide and low density operational areas, often with complex topography

- Expansion of wastewater treatment (and associated sludge disposal), which has almost tripled in recent decades (Lentini, 2008), although it also presents new opportunities for biogas production

Increased energy costs have direct implications for service affordability and sector financing, especially considering that the vast majority of water utilities struggle to attain self-financing and that sector investment, and sometimes even operation and maintenance, is often financed through state budgets (Jouravlev, 2004; Fernández, 2009; Ferro and Lentini, 2013). With more efficient operation, many water utilities would be able to reduce energy costs by 10% to 40% (Rosas, 2011), and even more (up to 75%) in wastewater treatment – savings that could help expand service coverage to the poor, improve service quality, and make bills more affordable for customers.

13.3 The way forward

The search for appropriate response options is still a major challenge for Latin American and Caribbean countries. Regional experience suggests that the most promising strategies to more efficiently manage the water–energy nexus include the following:

- Development of effective coordination mechanisms between water and energy authorities, at both national and river basin levels, to ensure their policies, instruments and objectives are mutually consistent and do not undermine each other. An important prerequisite is better availability and access to accurate and consistent water and energy data as well as facilitating dialogue among stakeholders on relevant issues.

- Improvement of water and energy regulatory frameworks, and harmonization of control, policy-making and financial mechanisms, with particular attention to multipurpose water use, requirements for approval of dam projects, resource conservation and reuse, demand management, watershed protection, strategic planning, and appropriate tariff/pricing and subsidy design.

- Transition to integrated water resources management (Solanes and Jouravlev, 2006), with emphasis on:

    - Water authorities that are independent from sector influences, in order to ensure objective decision-making, and whose powers and resources are in line with their responsibilities

    - An effective conflict prevention and resolution system – including an efficient judicial system that is capable of resolving conflicts with low transaction costs and consistent results – and river basin organizations that integrate all relevant stakeholders

    - Water (re)allocation systems that promote investment in the development and conservation of water resources and, at the same time, avoid monopolies and facilitate coordination and control in the public interest, taking into consideration the particular characteristics of the water system and the river basin

    - Protection of watershed ecosystem services and environmental flows, as well as integration with watershed and forest management, as key strategies for ensuring water and energy sustainability

CHAPTER 14

Africa

UNECA

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In Africa the quest for water security has always been linked to the quest for energy security (African Water Vision 2025; UNECA, 2000). Energy security will be achieved only when society obtains access to dependable, modern energy services. Because most of sub-Saharan Africa's population is predominantly rural (70%) (World Bank, n.d.*a*), achieving rural energy security is a prerequisite for equitable and sustainable development. Sub-Saharan Africa is characterized by low consumption of commercial energy and high dependence on traditional fuels. The majority of the rural population relies on traditional energy supplies, mainly unprocessed biomass, the burning of which causes significant pollution and health concerns (Section 3.1).

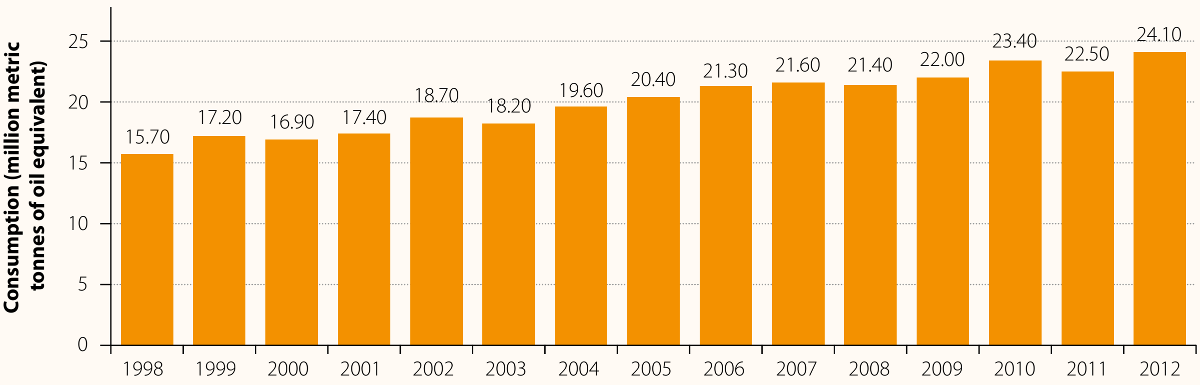
Water as a source of power has a vital role to play in responding to the socio-economic crisis facing Africa. One aspect of the interdependence between water availability and development can be seen by the introduction of electricity to rural areas in Africa. The impact is immediate and visible.

14.1 Energy use

Sub-Saharan Africa is the least electrified of all major world regions, with 57% of its population without access to electricity in 2011 (IEA, 2012*a*). Excluding South Africa, the entire installed generation capacity of sub-Saharan Africa is only 28 GW, equivalent to that of Argentina (World Bank, n.d.*b*). Sub-Saharan Africa consumes126 kWh/year electricity; including South Africa causes this figure to rise to 447 kWh/year. The variation between countries and regions is exacerbated by the urban–rural divide: the sharp disparity is evident in the low figure of 7.5% electrification in rural areas. The trend of electricity consumption in Africa over the past decade is shown in Figure 14.1. A steady increase on the aggregate is expected to accelerate with the current rapid economic growth being experienced in many African countries.

With increasing demand, some progress has been made and overall electricity production has more than doubled in the past two decades (Figure 14.2). Nevertheless, sub-Saharan Africa is the only region in which the absolute number of people without access to electricity is increasing. It is estimated that without major policy action and increased investment in the electricity sector, 650 million people will be living without electricity in sub-Saharan Africa in 2030 compared with some 500 million today (IEA, 2011*b*). Fortunately, this rapidly growing

FIGURE 14.1 **Trends in hydropower consumption in Africa (1998–2012)**



Source: Statista/BP (http://www.statista.com/statistics/265560/african-hydropower-consumption-in-oil-equivalent/) (Accessed Sep 2013).

region of the world also has the greatest hydropower potential of any region (Section 3.3.3).

Addressing the development challenges of low life expectancy and high infant mortality, illiteracy and fertility rates in sub-Saharan Africa requires improved access to electricity, particularly by poor and rural communities. Improving access to electricity for the majority of the population living in peri-urban and rural areas is critical. Indeed, access to electricity is essential for powering local industry and thus generating employment, alleviating poverty, improving public health, and increasing access to modern information and education services. With growth in the African economy there will also be a need to provide additional electricity to urban centres and industries.

14.2 Hydropower

Hydropower is an important source of modern energy. Hydroelectric power supplies 32% of Africa's energy (UNEP, 2012). Although endowed with considerable hydropower potential, African countries have developed only a small fraction of it – about 8% (Box 14.1). The key hubs, sometimes called 'water towers', for potential hydropower generation are in the Congo River basin, the Fouta-Djallon highlands in West Africa and the Ethiopian highlands in East Africa – in fact 60% of the region's hydropower potential is in the Congo and Ethiopia.

14.1 BOX

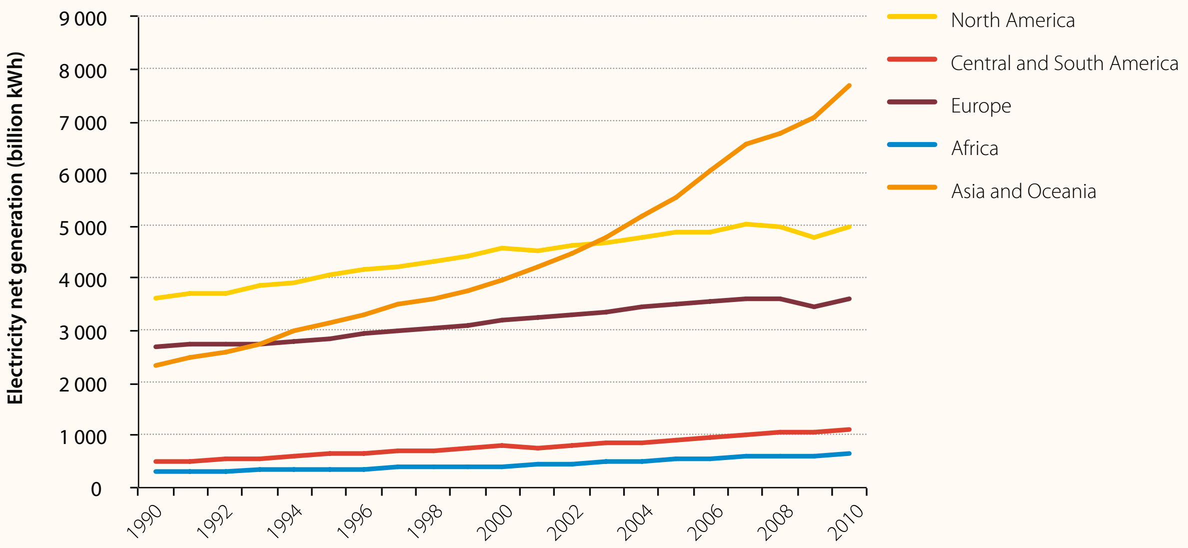
Key facts on hydropower in Africa

- Economically feasible hydropower potential: 842,077 GWh/year (Table 3.3)
- Potential developed: 8% (Figure 3.11)
- Countries with the largest hydropower potential: Congo, Ethiopia, Cameroon
- Countries with the largest installed hydropower: Egypt, Congo, Sudan, Nigeria
- Hydropower in operation (2011): ~26 GW
- Hydropower under construction (2011): ~14 GW
- Key river basins for future hydropower development: Congo, Nile, Zambezi
- Proposed projects: Grand Inga Project on the Congo River, estimated cost US$50 billion. At 40,000 MW, this would be world's largest hydropower project. The Congo is the second richest river in the world for fish. Fish diversity could be threatened by insensitive hydropower development.
- Negative impacts of hydropower: Downstream fisheries and ecosystems have been heavily impacted by large hydropower projects, for example in the Zambezi and Senegal basins. Dams have displaced 400,000 people across Africa.

Source: UNECA, with values from Aqua-Media International Ltd, 2012. See also UNSD (2013) and Kumar et al. (2011).

14.2 FIGURE

Recent trends in electricity production for world regions including Africa

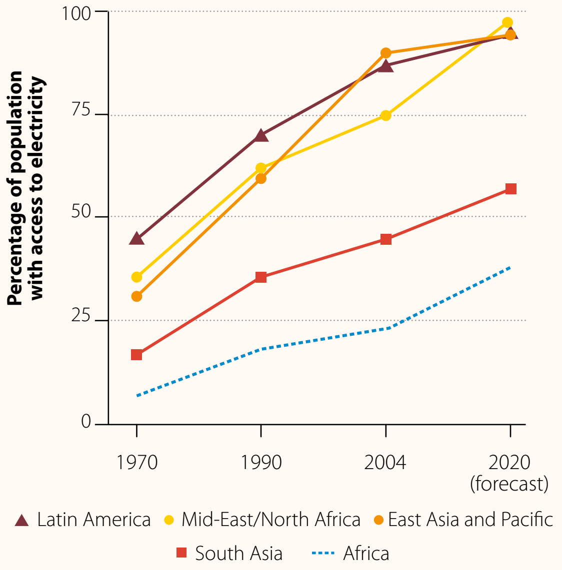


Source: UNECA, with data from US Energy Information Administration 'International Energy Statistics' Web page (http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm) (Accessed Sep 2013).

> ***Sub-Saharan Africa** is the only region in which the absolute number of people without access to electricity is increasing*

FIGURE 14.3

Global electricity access rate



Note: The graph shows that more than 500 million people in sub-Saharan Africa lack access to electricity. Connection rates are as low as 5% in rural areas.
Source: Cosgrove-Davies (2006).

Low exploitation of hydropower potential can be explained to a significant extent by the fact that most African countries are dependent on external resources for major infrastructure projects. During the 1980s, development partners shied away from major projects, especially dams. Africa currently faces an infrastructure funding gap of US$31 billion a year, mainly in power (World Bank, 2010*d*). Another challenge facing most sub-Saharan African countries with substantial hydropower resources stems from the difficulties in adopting the long-term policy measures necessary for sustainable development of these resources.

Water and energy in Africa is synonymous with hydropower in terms of potential available energy for present and future use. Hydropower is a renewable energy and thus preferable to many other energy sources (i.e. fossil fuels) in terms of sustainability. In light of the lack of exploitation to date, hydropower remains the main energy option to promote sustainable development and to power trade, regional integration and poverty eradication in Africa. Hydropower provides the opportunity for good long-term and trans-generational investment in clean energy for the growth of Africa, economically, socially and environmentally. In the context of climate change, especially where models predict reductions in river flows, hydropower will still provide the bulk of energy in an optimal mix with other sources, including geothermal, wind and solar power (see Chapter 25 [Volume 2] for the case study 'The role of geothermal energy in Kenya's long-term development vision').

14.3 Access to services

The most important variable at the human level when it comes to water and energy is whether the service can be accessed – when, where and in adequate quantity and quality – by every individual who needs it. The level of access strongly correlates to socio-economic development and is a critical prerequisite to poverty reduction globally and in Africa in particular. Figure 14.3 shows global electricity access; it is evident that Africa lags behind other regions. This presents a great challenge, which can also be seen as a great opportunity: to develop the great hydropower potential in a clean, efficient way, having learnt from the rest of the world so as not to repeat the negative aspects of their experiences.

PART 4

RESPONSES: FOSTERING SYNERGIES AND MANAGING TRADE-OFFS

CHAPTERS

The first three parts of this report have demonstrated how water and energy are highly interdependent, and that choices made in one domain have impacts on the other – direct and indirect, positive and negative. These choices also collectively impact upon, and are affected by, other water- and energy-dependent sectors. Water and energy are both drivers and inhibitors of economic growth and improvement of human health. They are enablers for widespread poverty reduction and job creation, and are generators of well-being. Many internationally agreed development goals, including nearly all the MDGs, depend on major progress in access to safe water, adequate sanitation and reliable sources of energy. Decisions about water and energy sharing, allocation, production and distribution between different users and uses have important social and gender equality implications, as they ultimately determine the resources and services that can be made available at the household and community levels.

Growing demand for finite water resources is leading to increased competition between the energy sector and other water-using sectors of the economy, principally agriculture and industry. Climate change creates additional pressures. All around the world, droughts, heatwaves and local water shortages in the past decade have interrupted electricity generation, with serious economic consequences. At the same time, limitations on energy availability constrain the delivery of water services.

Because of their similarities, and despite their differences, the water and energy domains face common challenges. Water is a major, and generally inefficient, user of energy; while energy is a major, and generally inefficient, user of water. However, the respective incentives facing the two domains are asymmetrical: energy users have little or no incentive to conserve water due to zero or low prices, but water users normally do pay for energy, though prices are often subsidized.[32] Water and energy prices are strongly affected by political decisions and subsidies that support major sectors such as agriculture and industry, and these subsidies often distort the true economic relationship between water and energy. Particularly for water, price is rarely a true reflection of cost – it is often even less than the cost of supply. Historically, the price of water has been so low that there has been little or no incentive to save it in many places around the world.

Finally, a crucial aspect of burgeoning global demand for water and energy is the resulting pressure on water resources and degradation of ecosystems. Ecosystems provide the natural enabling environment for energy provision and water flows. They also deliver energy, often depending on water to do so.

Recognition of this interconnectedness has led some observers to call for a greater level of integration of the two domains. Although this may be possible and beneficial under certain circumstances, an increased level of collaboration and coordination would create favourable outcomes in nearly all situations.

How should policy-makers and decision-makers respond to the dilemmas, risks and opportunities presented in this report? Various solutions have been explored. Their most common theme is improving the efficiency and sustainability with which water and energy are used, and finding win–win options that create savings of both, which can become mutually reinforcing (creating synergy).

Not every situation offers such opportunities. Where competition between different resource domains are likely to increase, the requirement to make deliberate trade-offs arise. These trade-offs will need to be managed and contained, preferably through collaboration in a coordinated manner. To do this, better and sometimes new data will be required.

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[32] The energy bills of water utilities often go unpaid, as well as vice versa (Hussey et al., 2013). In South Asia and elsewhere, farmers pay highly subsidized rates for publicly supplied electrical power (Molle and Berkoff, 2008, ch. 9). Globally, 'underpricing power costs the sector at least $2.2 billion a year in foregone revenues… [in Africa] neither commercial nor residential customers [of power] are close to paying full cost recovery prices' (AICD, 2012, pp. 191–192).

CHAPTER

15

Creating an enabling environment for change

WWAP | Richard Connor, Lyndsay Mountford, Frederik Pischke and James Winpenny

Problems arise when water and energy policies are formulated in isolation. There are, fortunately, examples of policies and actions that benefit both domains (win–win projects, optimum trade-offs). Sometimes these synergies arise unintentionally, by policy-makers acting with an eye towards their own domains. But accidental synergy cannot be relied upon to produce enough of the positive common actions necessary to address growing problems evident in both domains.

A coherent policy – which is to say an adequate public response to the interconnectedness of the water, energy and related domains – requires a hierarchy of actions. These include:

- Developing coherent national policies affecting the different domains
- Creating legal and institutional frameworks to promote this coherence
- Ensuring reliable data and statistics to make and monitor decisions
- Encouraging awareness through education, training and public information media
- Supporting innovation and research into technological development
- Ensuring availability of finance
- Allowing markets and businesses to develop

Together these actions make up the *enabling environment* necessary to produce the changes needed for sustainable and mutually compatible development of water and energy.

At the outset, the different *political economies* of water and energy should be recognized, as these affect the scope, speed and direction of change in the respective domains. While energy is often synonymous with big business and carries great political clout, water is not and generally does not. There is a marked difference in the pace of change visible in the energy and water domains, driven by the evolution of markets and technologies (Hussey et al., 2013; Sections 1.2, 1.3). These forces also drive changes in governance, which happens at a different rate in the two domains. Unless those responsible for water step up their own governance reform efforts, the pressures emanating from developments in the energy sphere will become increasingly restrictive and make the tasks facing water planners, and the objective of a secure water future, much more difficult to achieve. And failures in water can also lead directly to failures in energy.

National energy and water policies *need to be compatible and coherent*

National energy and water policies need to be compatible and coherent. Policies in response to climate change are a specific case in point: efforts to mitigate GHG emissions (e.g. through hydropower or biofuels) may place greater strain on water resources, and development of new water sources (e.g. through desalination) imperils national emissions targets.

Governments also need to cultivate widespread awareness of the water–energy nexus through *public information fora*, social and political conversation, and education. It is incumbent on professional communities in the water and energy domains to meet and discourse with each other to a much greater extent than they do at present.

Legal and regulatory frameworks should be created to channel reforms and establish rules and sanctions for infractions by users, including businesses. Calls for closer regulation and greater transparency, monitoring and local community engagement are part of the public and political reaction to the potential impact on water from the development of unconventional sources of oil and gas; for example, fracking in Argentina, Mexico, the USA and in Europe, and the development of oil (tar) sands in Canada (Sections 3.2.1, 10.5).

Institutions involved in policy formulation (e.g. ministries, planning commissions, committees, local government bodies) must be mindful of the water–energy nexus and incorporate it into their planning and decision-making systems. Integrating water and energy into decisions is easier said than done. It will take different forms in different countries, at different administrative levels in each country, but it is important to make some progress in this direction. Where river basin organizations (RBOs) exist, for instance, it is sensible to include representatives from energy, power and water communities in their stakeholder fora – some RBOs even use the terminology 'parliaments' to denote a style of debate and resolution. The *collaboration on resource planning* approach was recognized some years ago in a key report of the USA's Department of Energy:

Research into how much of a reduction in energy demand *can be achieved from increased water efficiency and vice versa would support policy-makers and investors in making more resource efficient strategies and investment choices*

> Collaboration on energy and water resource planning is needed among federal, regional, and state agencies as well as with industry and other stakeholders. In most regions, energy planning and water planning are done separately. The lack of integrated energy and water planning and management has already impacted energy production in many basins and regions across the country…
>
> Mechanisms, such as regional natural resources planning groups, are needed to foster collaboration between stakeholders and regional and state water and energy planning, management, and regulatory groups and agencies. These types of collaborative efforts are needed to ensure proper evaluation and valuation of water resources for all needs, including energy development and generation (USA DOE, 2006, p. 11).

Institutional capacity development can play an important role in fostering interdisciplinary and interministerial approaches that support the integration of interdependencies in decision-making through knowledge and technology transfers between different governmental levels and sectors, and through the exchange of experiences.

The Strategic Environmental Assessment[33] produced by the Mekong River Commission exemplifies an integrated approach to water and energy in the context of a major transboundary river basin. This assessment considers the interdependencies between energy generation and the availability of water, and the impacts of alternative policies for energy and water resource development and management on ecosystems, social systems and economic development over a 15-year perspective (MRC, 2009).

For major infrastructure, *integrated planning* and the *joint design of programmes and investments* between energy and water experts and managers may be appropriate. Sharing data for modelling, and agreeing on common assumptions, is clearly important. There is a role for collaborative resource planning, identifying synergies and optimizing and negotiating trade-offs. Some of these factors can be mediated in local planning decisions. All such actions would be easier with a better mutual understanding of the economic gains to be had from collaboration and cooperation between the two domains.

With an annual investment of US$198 billion globally on average over the next 40 years, water use can be made more efficient, enabling increased agricultural, biofuel and industrial production (UNEP, 2011*b*). Investing $170 billion annually in energy efficiency worldwide could produce energy savings of up to $900 billion per year (SE4ALL, 2012), and each additional $1 spent on energy efficiency in electrical equipment, appliances and buildings avoids more than $2, on average, in energy supply investments (US EIA, 2010*a*). Research into how much of a reduction in energy demand can be achieved from increased water efficiency and vice versa would support policy-makers and investors in making more resource efficient strategies and investment choices. For example, water decoupling (i.e. using less water

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[33] General guidance on the Strategic Environmental Assessment (SEA) of plans and programmes is provided by the Protocol on the SEA to the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention) (UNECE, 2011*b*).

and causing fewer environmental impacts per unit of economic output) is possible and already happening in many regions and sectors, offering win–win opportunities, especially in developing countries (UNEP-IRP, 2012).

Although the bulk of water and energy infrastructure has been traditionally provided by the public sector, the size of future investment required for both domains means that the gap cannot be filled solely from public finance, and major recourse to *private finance* will be essential. However, public actions will be required to establish adequate and predictable investment environments and to mitigate some of the risks that currently deter private financiers in some of the poorest countries. Sound regulatory policies, public–private partnerships, public expenditure reviews and results-based financing are some approaches proposed to help enlist private finance (Section 5.1).

Water and energy governance should be *gender sensitive*, recognizing women as important decision-makers in all areas of water and energy governance at all levels and ensuring their due voice and influence in the shaping of policy and practice. Governments can benefit from prioritizing full and equitable access to water and energy in national development plans and poverty reduction strategies, and promote investments that alleviate the unpaid work burden of women and children.

Other key measures include the establishment of accountability frameworks based on clear gender equality benchmarks and gender audits to monitor the gender-related performance of the two domains; the implementation of positive measures to increase the enrolment of young women in technical areas related to water and energy; the positioning of qualified women as leaders of innovation in water and energy efficiency; and the generation of gender-disaggregated data required to measure progress.

15.1 Breaking down barriers – and building bridges

Policy-makers, planners and practitioners in water and energy need to take steps to overcome the barriers that exist between their domains. ‘The disconnect between water and energy policy is driven in large part by the failure of water and energy practitioners to engage with and fully understand one another’ (Cooley et al., 2011, p. 9). That being said, the disconnection can also be attributed to the fact that each domain has been traditionally expected to focus on a narrow mandate in meeting its own aims and fulfilling its own targeted responsibilities. As a result, there is often little or no incentive to initiate and pursue coordination or integration of policies across sectoral institutions (Section 5.1).

Previous editions of the United Nations *World Water Development Report* (WWAP, 2009, 2012) urged water policy-makers to *think outside the box* to address the many ways in which water is impacted by events and decisions arising outside water ‘borders’ as they are commonly viewed. By the same token, policy-makers in other areas of social and economic life should acknowledge both their own impact on water and the impact of water on their policies, for example as an input or constraint. Nowhere is this more true – or more urgent – than for energy. The water–energy nexus can be regarded as one of the first and most important steps outside the box (or ‘silo’) for both domains. Other linkages are also important to explore where these can improve policy-making; for instance, those between energy, water and land (EU, 2012); between water, food, energy and climate (WEF, 2011); and with the environment. Water and energy practitioners need to work collaboratively towards a coherent response to common challenges.

> ***Each domain** has been traditionally expected to focus on a narrow mandate in meeting its own aims and fulfilling its own targeted responsibilities. As a result, there is often little or no incentive to initiate and pursue coordination or integration of policies across sectoral institutions.*

In some countries the same national institution is responsible for planning, management and service provision for water and power (e.g. in Pakistan the Water and Power Development Authority [WAPDA]; in Guinea where the Ministry of Energy is also responsible for water resources development; and in Zambia where the

Ministry of Energy and Water Development looks after both portfolios). However, effective collaboration does not necessarily require that responsibilities for water and energy be combined into the same institutional portfolio, nor does doing so assure coherent cooperation.

Urban water and power utilities have much in common, and much to learn about each other's reform agenda – both its successes and its failures. Examples in the realm of distribution of urban water and power services demonstrate that the common aims of efficient use and reduction of waste could be achieved by focusing on programmes to reduce unaccounted-for water, as water is a profligate user of energy (see Chapter 28 [Volume 2] for the case study 'Water and energy linkage in Austin, Texas, USA'). Likewise, the aim of improved bill collection by both services could be attained more easily if a single agency coordinated collection for both utilities.

Although there is scope for synergies and win–win results, there is also an array of situations where competition for resources or genuine conflict between water and energy aims can arise, requiring some degree of trade-off. Dealing with trade-offs may require and benefit from negotiation, especially where international issues are involved, as in the upstream–downstream tensions between hydropower and irrigation over the use of water in Central Asian countries (Sections 10.2, 6.6) and the Mekong basin (Section 11.1). Likewise, conflicts have arisen in many countries, for example in Chile between farmers and hydropower companies over the timing of water releases and unused water rights, which has been somewhat mitigated by the imposition of taxes on the latter (Section 13.1).

15.2 Economic instruments

There is no silver bullet to bring about the kind of changes and reforms considered in the above paragraphs. Governments have to use a variety of measures – incentives and well as sanctions, a mixture of persuasion and penalties. Economic incentives and market-based instruments should be considered in policy packages designed to change behaviour towards water and energy. They can greatly reinforce the impact of other types of measures, such as regulations, public awareness campaigns, exhortations and technological developments. This does not imply that the market should have the final word in allocating water and energy resources and services. Pricing should be used sensitively with a view to its social and distributional impact. Pricing can, however, add a crucial boost to other water and energy policies.

> ***Although there is scope for synergies** and win–win results, there is also an array of situations where competition for resources or genuine conflict between water and energy aims can arise, requiring some degree of trade-off*

Economic instruments include prices, taxes, pollution charges, subsidies, and markets for buying and selling a service, a resource or the rights to use the service or resource.

Economic pricing of energy and water services can more closely reflect the economic cost of their provision; provide sufficient revenues for continued operation and maintenance; and avoid waste and distortions due to under-pricing. In 2005, Komives et al. reported that 'global tariff surveys indicate that the majority of electricity and (particularly) water utilities charge tariffs substantially below levels commensurate with full cost recovery. A significant proportion of utilities charge tariffs that do not even cover operating and maintenance costs.' (Komives et al., 2005, pp. 165–166). In many countries, subsidies in water and energy are widespread and impose a large and growing fiscal burden. Although it is unrealistic to expect a rapid reversal of this situation, there is scope in many cases for adjusting tariff structures and targeting subsidies to protect the poorest and most deserving consumers, while reducing some of the worst distortions and waste caused by subsidy dependency (OECD, 2009, 2010*b*,*c*).

Even 'economic' tariffs that fully recover financial costs exclude important external costs that the use of water and energy imposes on others. This is partly a matter of internalizing externalities such as pollution and GHG emissions through pollution charges, carbon taxes and so forth. It is also partly a matter of reckoning the opportunity costs of using resources for one purpose, when this deprives some other potential user. Tools such as environmental economic valuation can be used to reflect these costs at the project level.

Though energy (generally fuels) is systematically traded on commodity exchanges, water trading is much more difficult and contentious as it is based on tradable 'rights' rather than a commodity. However, water trading between major use sectors is possible in some circumstances and provides an economic mechanism for resolving allocation conflicts. Trade could be either seasonal or permanent. Although water markets have been created in a few countries (e.g. Australia, Chile, USA) trading depends on an appropriate legal framework and effective regulation designed to avoid transfer of negative externalities and monopolization of water rights and to reduce transaction costs. The large volume of water required for thermal power on a long-term basis is likely to need permanent transfers; for example, by buying out farmers' rights. Such transactions tend to arouse social and political resistance, although there are cases of cities securing their water by such deals.

The imposition of a *non-consumptive water use tariff* at an economic level, applicable to power generation and other sectors such as industry and mining competing for bulk water, could provide a level playing field for charging, and create incentives for the more efficient use of water all round. Imposing higher non-consumptive tariffs on thermal and hydropower generation would clearly signal and incentivize the need to adopt more water efficient processes. This would apply whatever water tariffs were charged to other sectors.

15.3 Role of the United Nations system and the international community

Local, national and regional policies and actions can often benefit from a strong endorsement from the international community, in such areas as (a) cooperation and information exchange in state-of-the-art public policy formulation; (b) government, consumer and investor awareness and commitment; (c) application of integrated resource efficiency planning; (d) capacity development on existing strategies and tools; and (e) improvements in the availability of relevant and robust data.

The United Nations Conference on Sustainable Development (Rio+20) in 2012 explicitly acknowledged that water is at the core of sustainable development as it is closely linked to a number of key global challenges. The United Nations General Assembly in 2012 also recognized the critical role that energy plays in the development process. However, it is particularly telling that there is no mention whatsoever of water in the energy section, or of energy in the water section of the outcome document. The Bonn 2011 Nexus Conference,[34] organized in preparation for Rio+20, focused international and national attention on the water–energy–food nexus and the solutions such an integrated approach can provide.

***Economic pricing of energy and water services** can more closely reflect the economic cost of their provision; provide sufficient revenues for continued operation and maintenance; and avoid waste and distortions due to under-pricing*

In practice, different people in different departments, if not different agencies, are responsible for funding decisions, project development and policy-making. This holds true at all levels of administration and explains why integrated energy and water policies are rare (Section 5.1). However, in the work of the United Nations system, other international regional organizations, development banks and bilateral development agencies, many programmes and projects exist aiming to address the interplay between energy and water. This points to a project-by-project approach to deliver context-specific support. The coordination mechanisms of the United Nations system, UN-Water and UN-Energy continue to play leadership roles in providing a platform for cooperation with civil society to formulate coherent responses on water and energy – issues that cut across the mandates of the international system. The recognized need for separate sustainable development goals dedicated to water, food and energy security, which must be independent of each other but closely related and coordinated, provide an excellent opportunity for UN-Water and UN-Energy to assume a strong leadership and facilitatory role.

In the realm of financing, the international community has an obligation to support those people most in need

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[34] For more information, see http://www.water-energy-food.org/en/conference.html (Accessed Apr 2013)

– the 'bottom billion' – in countries considered too risky by lenders to fund provision of basic water, sanitation and modern energy services and nutrition (Box 1.3). International agencies also have programmes to help increase efficiency in public spending and to ensure that the regulatory framework in a country is strong enough for public–private partnerships to function to the benefit of society.

The international community can bring actors together and play a catalytic role in supporting national, subnational and local governments as well as utility providers, who have a major role in how the water–energy nexus plays out at the national and relevant local levels. Though the energy and water service sectors function in different ways, external support can help authorities in charge of public policy formulation, regulation, planning and financing as well as utilities in both sectors learn from each other in their reform processes and provide a space to work with each other to realize efficiency gains and plan for future demands.

The same is true for the relationship between the United Nations and the private sector. The UN Global Compact's CEO Water Mandate[35] provides a platform to facilitate private sector support to governments and society at large in order to realize overall economic results, social benefits and environmental protection. One approach would be to assist companies in the formulation, development, implementation and disclosure of appropriate water sustainability policies and practices as they relate to energy.

Without reliable monitoring data, it is difficult to devise good projects, programmes and policies (Chapter 4). If countries are expected to collect new types of data and include water–energy indicators, particularly when developing a post-2015 development agenda, the international community needs to help strengthen the collectors and distributors of primary data in countries – including national statistics agencies and water, energy and environmental authorities and users. Strengthening data collection entities and disclosing the gains of water and energy policies can eliminate blind spots in water and energy management, facilitate better public policy formulation, increase the visibility of co-benefits, and provide the basis for an open dialogue when difficult trade-off decisions need to be taken.

The increasing synergy between water and energy can drive change and innovation. The international community can play a key role in resolving this multifaceted issue. Its voice is needed to ensure that sustainability and equity are factored into decisions about the use of resources nationally as well as internationally. Transboundary cooperation, international trade and regional energy grids can all be vehicles for delivering benefits to nations and their people. The independent and strong voice of the international community can help ensure that social and environmental messages get through, alongside economic considerations, to target the 'triple bottom line' of overall economic progress, social equity and environmental protection.

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[35] For more information, see http://ceowatermandate.org/ (Accessed Apr 2013)

CHAPTER 16

Responses in practice

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The interplay of water and energy, and the scope for fostering synergies and managing trade-offs between them, is illustrated below in the contexts of agriculture, industry, cities, ecosystems and power. This chapter summarizes the response options outlined in earlier parts of this report with some specific examples.[36]

16.1 Energy-smart and water efficient agriculture

Applying energy efficiency measures at the farm level (Table 6.3) and at all stages along the agrifood chain can bring direct savings through technological and behavioural changes, and indirect savings through co-benefits derived from the adoption of agro-ecological farming practices. Avoiding food wastage can result in considerable savings in energy, land and water.

Knowledge-based precision irrigation can provide flexible, reliable and efficient water application, which can be complemented by deficit irrigation and wastewater reuse. Crops often take up only half of the irrigation water applied, so there is clearly potential to improve water use efficiency of mechanical irrigation systems, which would also result in less demand for electricity or diesel fuel for pumping. However, while irrigation losses may appear high, a large part of these losses usually return to the water body in the form of return flow or aquifer recharge (Section 6.6), often laden with nutrients and other chemicals. Cases have been reported where more efficient, but energy intensive irrigation increases the consumptive

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[36] Yet more examples are presented in Volume 2.

BOX 16.1

Groundwater, irrigation and energy: Responses to an unsustainable situation in Gujarat, India

The issue of groundwater overdraft in India has been well known for decades. In the state of Gujarat, free groundwater and subsidized electricity to pump it contributed to severe groundwater overdraft, near bankruptcy of the State Electricity Board, and poor power supply to farmers and other rural residents. The textbook solution seemed simple enough: price groundwater and electricity to reflect their value. However, those who tried to implement these solutions did not appreciate the political realities in India. Efforts to rationalize pricing were met with great resistance by farmers. Politicians lost their jobs and external funds for modernizing the system were withdrawn. The State Electricity Board continued to generate great losses and was unable to meet the needs of the rapidly growing economy. Farmers had to accept poor quality power supply as the cost of their 'free' supply, and the pressure on aquifers was substantial.

An alternative approach, called the Jyotigram Scheme, diverged from the textbook approach and embraced subsidies as part of a strategy. But rather than viewing subsidies as a default component of free electricity supply, the Jyotigram Scheme focused on providing rationally managed subsidies where needed, and pricing where possible. Under the programme, rural Gujarat has been completely rewired. Villages are given 24-hour, three-phase power supply for domestic use and in schools, hospitals and village industries, all at metered rates. Farmers operating tubewells continue to receive free electricity, but for 8 hours rather than 24 and, importantly for the satisfaction of farmers, on a pre-announced schedule designed to meet their peak demands.

The separation of agricultural energy from other uses and the promise of quality supply were sufficient to gain political and social backing for implementation. The Jyotigram Scheme has now radically improved the quality of village life, spurred non-farm economic enterprises, and halved the power subsidy to agriculture. While groundwater itself is still free, the programme has indirectly raised the price of groundwater supply from tubewell owners in the informal market by 30% to 50%, thus providing a signal of scarcity, and reducing groundwater overdraft. The solution may not be perfect, but it has proved to be implementable and it has brought substantial improvement inside and outside the water sector.

Jyotigram is now a flagship programme of the Government of India, replicated in Punjab, Haryana, Madhya Pradesh, Karnataka and Andhra Pradesh.

Source: IWMI, from Shah et al. (2004, 2008) and Shah and Verma (2008).

__Energy audits__ to identify and reduce water and energy losses and enhance energy efficiency can result in substantial energy and financial savings, with savings of between 10% and 40% reported

use of water and reduces return flows, leading to more pressure on aquifers.

Dam and reservoir design that accommodates fisheries and aquaculture can allow continued food production from rivers that are dammed for hydroelectric development. Optimizing the management of storage capacity of catchments, including soils, groundwater and reservoirs, offers scope for greater efficiency; for example, drawing upon groundwater reserves at times of low reservoir capacity and enabling groundwater to recharge when reservoirs are full (Box 2.2).

While access to inexpensive fossil fuel combined with access to versatile, affordable low-maintenance diesel engines in Bangladesh has benefited smallholder farmers without over-exploiting water resources (Section 6.6), energy subsidies in the drier parts of India have had detrimental effects on groundwater levels. In Gujarat, one of the drier states in India, policies to ration farm power supply, and thus water supply, have been recommended to encourage farmers to use water more sparingly (Box 16.1). In Argentina and Mexico, electricity subsidies are having a damaging effect on groundwater aquifers while mainly benefiting the most prosperous farmers (Chapter 13). The political difficulties of reform cannot be underestimated, but reform of energy subsidies could benefit both energy and water domains in such situations.

In areas with sufficient endowments of surface water, modernization of existing canal irrigation systems to improve services may encourage farmers to reduce their groundwater use as it is often more expensive (due to the cost of pumping) than surface water supply. These systems can have multiple purposes – such as crop production, domestic use, animal husbandry and support of small industries.

16.2 Innovating cities

It has been suggested that more than half of the water demand and water-related energy consumption in some

16.2 BOX

Energy efficiency generates savings for water supply systems

The Improvement of Energy Efficiency (IEE) project of the Water Authority of Jordan (WAJ) is focusing on demand-side energy reduction in pumping stations and promoting institutional change through private sector participation. The case was presented at the Amman–Cologne Symposium 2011.

'In initial energy audits, the IEE project analysed the electricity consumption and improvement potential of key pumping stations and developed detailed recommendations for implementation. Efficiency improvements in the range of 4%–65% of the electricity consumed are feasible in various pumping stations. This would reduce the annual energy use by 21 million kWh, representing about 1 mill. JOD [US$1.4 million] per year in energy cost savings for WAJ and hence improving cost recovery.'

'... An energy service company (ESCO) provides the funding for the repair and replacement of the pumping equipment, designs and installs the equipment, and takes over operation, maintenance and repair processes for a defined period. The remuneration of the ESCO for its services depends on the reduction of specific energy consumption (kWh/cbm[m^3] pumped) during the contract period, since the cost savings are shared between WAJ and the ESCO.'

'By this, a triple win situation is created: firstly a cost recovery improvement reduction, secondly the availability of new infrastructure at no cost for WAJ, and thirdly a reduction in greenhouse gas emissions.'

'The results from a pilot pumping station confirm an increase in average energy efficiency of 40%, which translates into a cost recovery improvement of approx. 120'000 JOD [US$170,000] per year, very low maintenance efforts for the enhanced equipment and an overall reduction of pumping station downtime.'

Source: Waleed K. Al-Zubari, Arabian Gulf University, from Rothenberger (2011, pp. 20–21).

cities in the USA could be saved just by implementing simple water conservation measures, such as leakage prevention, efficient water appliances and xeriscaping. Further measures include collecting, treating and reusing stormwater for low-risk purposes such as garden watering and building cleaning and maintenance. Advanced water treatment options (such as reverse osmosis and desalination) can contribute to increased water availability, but their additional energy requirements need to be offset by the use of efficient technology and renewable energy sources (Section 7.4). Energy audits to identify and reduce water and energy losses and enhance energy efficiency can result in substantial energy and financial savings, with savings of between 10% and 40% reported (Box 16.2).

Potential, thermal and chemically bound energy contained in wastewater can be harnessed and utilized. Potential energy offers limited opportunities for energy production. Thermal energy in wastewater comes from its temperature when leaving a building, which can be particularly useful in places where a large amount of energy is required for heating water, especially in colder climates. It can be used for pre-heating via heat exchangers or heat pumps and recent technologies are highly cost-effective.

Chemically bound energy in wastewater is due to its carbon content, which can be converted to methane under anaerobic conditions. Methane can be used for domestic cooking and heating, as fuel for vehicles and power plants, or for operating the treatment plant itself. Biogas is a source of green energy, which replaces fossil fuels and reduces the amount of sludge to be disposed of, as well as achieving financial savings for the plant (Section 5.2.4). Many wastewater treatment plants have been able to generate biogas from wastewater or sludge and convert it to heat or electricity (Box 16.3; Section 7.4.3). In Stockholm, public buses, waste collection trucks and taxis run on biogas produced from sewage treatment plants. The anaerobic water treatment technologies responsible

> ***Chemically bound energy in wastewater …*** *can be used for domestic cooking and heating, as fuel for vehicles and power plants, or for operating the treatment plant itself*

16.3

BOX

Recovery of energy from wastewater

The As-Samra wastewater treatment plant was inaugurated in 2008 to treat the wastewater of 2.3 million equivalent-inhabitants[a] of Amman and surrounding areas. The project is a public–private partnership for financing the construction and operation of public infrastructure in Jordan based on a build-operate-transfer (BOT) contract spanning 25 years.[b]

Wastewater is transported from Amman to the plant site by gravity over 40 km through a conveyor pipeline. The difference in elevation between the city and the treatment plant is significant, so the wastewater is under high pressure when it arrives at the plant. Instead of the pressure diverters commonly used to break the flow of this type of wastewater effluent, turbines have been installed to run on upstream wastewater flow and generate hydraulic energy, which is used on site. The treated effluent is again used to power hydraulic turbines generating renewable energy before it is released into the environment, joining a stream that directs the waters to King Talal Dam.

Biogas recovery has been implemented for the sludge digesters. Sewage sludge generated during the process is treated through anaerobic digestion. Biogas generated in the digester is captured and recovered in the form of electrical and thermal energy which is used on site. The plant is almost self-sufficient and requires very little power from the grid as it generates up to 95% of the plant electrical consumption from renewable sources (Solutions for Water, 2012).

Notes: [a] *Population equivalent (in wastewater monitoring and treatment) refers to the amount of oxygen-demanding substances whose oxygen consumption during biodegradation equals the average oxygen demand of the wastewater produced by one person. For practical calculations, it is assumed that one unit equals 54 grams of BOD per 24 hours (OECD Glossary of Statistical Terms at http://stats.oecd.org/glossary/).* [b] *This is the first BOT project for both Jordan and USAID. SWECO is the consulting company. The Swedish International Development Agency (SIDA) financed technical assistance during preparation, construction, commissioning, and 18 months of commercial operation of the project.*

Source: Waleed K. Al-Zubari, Arabian Gulf University.

for biogas production are particularly appropriate for warmer climates like those found across the Arab region (Section 12.2) among others. The use of dried faecal sludge as fuel is gaining momentum in several developing countries (Section 7.4.3).

16.3 Enhancing the role of industry

Large industry is well advanced in reacting to water and energy issues. Energy efficiency has been prioritized and driven by high energy prices and regulations concerning climate change and GHG emissions. More recently, water use efficiency has also taken on a higher profile. Industry's actions are the result of commitment to corporate policies, sustainability and CSR as well as a response to commercial, shareholder and consumer pressures (Chapter 8). These influences often extend through the industrial supply chain, with far-reaching impacts ranging from more sustainable practices to increased public awareness.

Carrying out water and energy audits to calculate balances and corresponding footprints is an important first step towards setting conservation and efficiency goals and targets. Many firms are adopting standards such as ISO 14000 (Environmental Management), ISO 5000 (Energy Management) and LEED (Leadership in Energy and Environmental Design). Specific measures include increasing water productivity through reuse, recycling or the use of reclaimed wastewater, and focusing on zero discharge technologies. In the energy domain the adoption of green technologies, such as energy efficient machinery, is increasingly an option. In terms of manufactured goods, considerable achievements have been made in the design and formulation of products specifically aimed at reducing the water and energy content or consumption of products and appliances. The formulation of detergents and washing machines is a notable example.

BOX 16.4

Initiatives for small and medium-sized enterprises

Small and medium-sized enterprises (SMEs) have been a focus for UNIDO, which has successfully set up National Cleaner Production Centres promoting Cleaner Production (CP) practices (UNIDO, n.d.*a*). These practices include:

- Good housekeeping to prevent leaks and spills and good operation and maintenance procedures and practices
- Input material change: using less hazardous or renewable materials or materials with a longer service lifetime
- Better process control, equipment modification and technology change for higher efficiency and lower rates of waste and emission generation
- On-site recovery and reuse of wasted materials within the company
- Production of useful by-products: transformation of wastes into materials for reuse or recycling outside the company
- Product modification to minimize environmental impacts during use or after (disposal) or to minimize environmental impacts of production

The UNIDO Transfer of Environmentally Sound Technology (TEST) programme (UNIDO, n.d.*b*) is associated with CP and supports industry by:

- Prioritizing a preventative approach to CP
- Addressing preventative environmental management and providing information on materials, energy and finance using environmental management systems (EMS) and environmental management accounting (EMA)
- Incorporating environmental management within corporate social responsibility (CSR) leading to sustainable enterprise strategies

Three areas of response specific to energy were identified for SMEs (UNIDO, 2008), although they could apply equally to water management:

- Target setting agreements. These can result in significant energy savings with long-term effects in changing attitudes and awareness.
- Energy management standards. By adopting standards, companies raise their image and a process of continuous improvement is set in place; energy efficiency becomes part of corporate culture.
- System optimization. This offers a fast return and encourages companies to adopt more fully integrated programmes.

Source: UNIDO.

Large companies and multinationals, particularly in the food and beverage sector, have been engaged for some time in improving water and energy efficiencies. Such companies see the value of efficiencies in both monetary and societal terms. An important policy issue is how to harness the combined capacity of small and medium-sized enterprises, which account for 70% of enterprises in most countries, and provide the financing necessary for them to generate efficiencies as a sector (Box 16.4).

16.4 Prioritizing ecosystem services

Expansions of all types of energy generation can be planned with an ecosystem perspective. IWRM, supported by systematic environmental flows assessment, is one framework for planning and allocating water at the basin level. The application of an ecosystems approach necessitates the valuation and use of natural infrastructure, supported by tools that include PES, remediation through sustainable dam and reservoir management, and strategic river basin investment.

Natural or green infrastructure can complement, augment or replace the services provided by traditional engineered infrastructure, which can enhance cost-effectiveness, risk management and sustainable development. Improved water resources and natural infrastructure in the form of healthy ecosystems can reinforce each other and generate additional benefits in the water–energy–food nexus (Box 16.5). The ongoing degradation of water and land resources in river basins, which threatens energy provision, could potentially be reversed through protection and restoration initiatives, providing resilience for increased climate variability and extreme events (Section 9.3).

> *In terms of manufactured goods, considerable achievements have been made in the design and formulation of products specifically aimed at reducing the water and energy content or consumption of products and appliances*

The economic value of ecosystems for downstream water users is formally recognized and monetized in PES schemes. These provide farmers with payments or green water credits from downstream water users for good management practices that support and regulate ecosystem services, thereby conserving water and increasing its availability and quality. In the Sarapiqui watershed in Costa Rica, upstream landowners are paid by a hydropower company for forest management

BOX 16.5

Natural infrastructure: Wetlands and hydropower in Rwanda

Rwanda presents a good example of how natural infrastructure (healthy wetlands) can complement and support built infrastructure (hydropower generation). In the mid-2000s, 'Rwanda experienced an electricity supply crisis that adversely affected its development prospects. This crisis was spurred in large measure by a steep decline in generation capacity at Ntaruka hydropower station which, along with the downstream Mukungwa station, provided 90 percent of the country's electricity'. The combined annual power production from Ntaruka and Mukungwa stations was around 120 GWh in 1998 and only 23 GWh (19%) in 2007. 'Ntaruka's reduced electricity generation was attributed to a significant drop in the depth of Lake Bulera, which acts as the station's reservoir. This decline in water levels in turn was precipitated by a combination of factors, including: poor management of the upstream Rugezi Wetlands, the headwaters of the watershed; degradation of the surrounding Rugezi-Bulera-Ruhondo watershed due to human activity; poor maintenance of the station; and reduced precipitation in recent years'. In response, 'the Government of Rwanda sought to restore the degraded Rugezi-Bulera-Ruhondo watershed by halting on-going drainage activities in the Rugezi Wetlands and banning agricultural and pastoral activities within and along its shores, as well as along the shores of Lakes Bulera and Ruhondo'. To compensate the local population for the subsequent reduction in access to key resources, which adversely affected livelihoods, 'the Government implemented a suite of agricultural and watershed management measures ... These measures included the construction of erosion control structures; the establishment of a belt of bamboo and Pennisetum grasses around the Rugezi Wetlands; planting of trees on the surrounding hillsides; distribution of improved cookstoves; the promotion of integrated and environmentally sound farming practices; and promotion of income-generating activities such as beekeeping. Today, through protection of the watershed surrounding the Ntaruka hydropower station, the plant has returned to full operational capacity'.

Source: UNEP, from Hove et al. (2011, pp. 1–2).

and restoration. The payment is based on the benefits generated from more reliable stream flow for hydropower optimization and the avoided costs of reservoir dredging due to reduced siltation.

In response to frequent severe flooding in the Magdalena River basin, the Government of Colombia has given central importance to an ecosystem-based approach to regulating planning and development to make sure that future economic activity in the river basin (which produces 86% of the country's GDP) – especially hydropower and agriculture – is compatible with its water resources (Section 9.3.3).

Sustainable dam management aims to design new and regulate existing structures with a view towards mitigating their impacts on natural ecosystems and society. The need for new dams can be reduced by retrofitting existing dams with power generation installations, and their operational efficiency can be enhanced by better integration of natural infrastructure in catchments. In the Rhine basin, the historical impact of extensive river modification is being partially mitigated by 're-naturalization' efforts such as the restoration of spawning and juvenile habitats for salmon (ICPR, 2010).

In the area of land management, conservation and remediation measures to avoid land degradation can lead to savings in water and energy consumption. Managing for multiple uses can reduce pressure on water resources by increasing water productivity; for example, when irrigation canals, downstream of a hydropower dam, are used for aquaculture or when household grey water from washing is reused on vegetable plots.

16.5 Power generation

With the exception of evaporative losses, hydropower generation is essentially a non-consumptive use of water, though the abstraction, storage and return of water can significantly impact other potential users (Sections 3.3.3, 6.2 and 9.2.1, as well as Chapters 10, 11, 13 and 14 for regional aspects). Multipurpose projects often include cross-subsidy from hydropower sales to irrigation and domestic consumption. In transboundary water management, the possibility of sharing power produced by multipurpose projects can be a common benefit that enables cooperation.

Thermal power generation development *involves the increasing potential for serious conflict between power, other water users and environmental considerations*

As Africa has not yet tapped in to its rich potential for hydropower development to a substantial degree (Chapter 14), water and energy policy-makers there have the ability to learn from the positive as well as negative aspects of hydropower implementation practices that nations in Europe, North America and elsewhere have undergone and where some countries with rapidly emerging economies appear to be heading. It can do so by using the rich experience that has been developed over the years, including existing sustainability frameworks and best practices.

However, hydropower development will not be easy. The IEA cautioned in its *World Energy Outlook 2012:*

> Several challenges threaten the development of hydropower in Africa, particularly the availability of funding. Political and market risks, as well as local environmental considerations are barriers to securing the large initial investments required. However, opportunities for funding are enhanced by several international programmes, including the Clean Development Mechanism under the Kyoto Protocol and a recent G20 initiative promoting investment in developing countries, which identified the Grand Inga project on the Congo River as a possible candidate for funding. Africa's energy needs are huge: 590 million of its people [57%] still lack access to electricity. Hydropower, both large and small scale, is an abundant source of clean energy that can make a major contribution to providing energy for all (IEA, 2012*a*, p. 226).

Other options for power generation present their own challenges. Thermal power generation development involves the increasing potential for serious conflict between power, other water users and environmental considerations. These trade-offs can sometimes be reduced by technological advances, but these may carry trade-offs of their own (Sections 3.3.1, 3.4, 5.1). Many new thermal power stations, especially in arid regions, incorporate cooling processes that minimize the abstraction of water.

Closed-loop (or wet recirculating with cooling tower) systems typically have high rates of consumptive water use and carry a heavy energy penalty, either in the direct input of energy to the process or in reduced power output. For these and other reasons, these processes tend to be costly. Dry cooling is resistant to drought, but power plant efficiency can decrease in warmer and drier climates, compromising their potential cost-effectiveness in many parts of the world. However, both systems allow more flexibility in the location of power plants, which can be sited with more consideration to other potential water users.

Heat generated in thermal power plants, which has to be dissipated with large volumes of cooling water, can be tapped for other purposes – for example in multi-stage flash distillation at desalination plants – with savings in both energy and water abstraction. This has implications in selecting the most appropriate locations for power and desalination plants. Some integrated hybrid desalination plants in the Middle East successfully combine power and water production in the same facility (Section 5.2.1). A variant of this is the use of solar-powered desalination processes (Box 12.2).

Alternative sources of water can be sought for power station cooling. Seawater is an option for coastal plants. Another option in response to the problem of obtaining large volumes of cooling water in arid regions is wastewater, used in 50 power plants in the USA including the Palo Verde nuclear power station (Section 5.2.2).

CHP stations seek the synergies from co-production of heat and power to directly serve neighbourhoods. Although management of the plants to meet the two different demands for heat and power can be challenging, CHP plans have off-setting advantages. In Denmark, CHP plants produce 50% of the total power generated (Section 5.2.3).

> ***Support for the development of renewable energy** will need to increase dramatically in comparison to support for fossil fuels in order to make a significant change in the global energy mix and, and by association, to water demand*

From a water perspective, power generated from solar PV and wind is clearly the most sustainable choice (3.3.4). However, their intermittent service needs to be compensated for by other sources of power (which *do* require water) in order to maintain load balances. Another renewable energy resource, geothermal power, holds enormous potential in certain locations where the geological conditions are suitable (Section 3.3.5). Global fossil fuel consumption subsidies totalled US$523 billion in 2011, which was almost 30% higher than in 2010 (IEA, 2012*a*). Financial support for renewable energy, by comparison, amounted to only $88 billion in 2011, and increased by another 24% in 2012 – mainly due to the expansion of solar PV in the EU (IEA, 2012*a*). Although this progress is encouraging, support for the development of renewable energy will need to increase dramatically in comparison to support for fossil fuels in order to make a significant change in the global energy mix and, and by association, to water demand.

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ABBREVIATIONS, ACRONYMS AND UNITS

Abbreviations and acronyms that appear only once in the Report or only in boxes, tables and figures are not included in this list. UN agencies are also not included. Organization and institute acronyms that appear in citations are given in full in the Bibliography.

BTU	British Thermal Unit
CHP	combined heat and power
CSP	concentrated solar power
CSR	corporate social responsibility
EIA	environmental impact assessment
EU	European Union
GDP	Gross Domestic Product
GHG	greenhouse gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IWRM	integrated water resources management
kWh/MWh/GWh/TWh	kilo/mega/giga/terawatt-hours
l.p.c.d.	litres per capita per day
LDCs	least-developed countries
MDG	Millennium Development Goal
OECD	Organisation for Economic Co-operation and Development
PES	payments for ecosystem/environmental services
PV	solar photovoltaic

BOXES, TABLES AND FIGURES

BOXES

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ISBN 978-92-3-104235-5

Set of three volumes
904 pages
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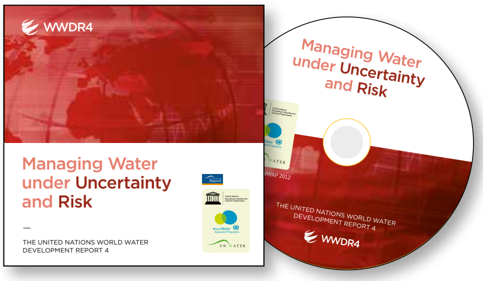

ASSOCIATED PUBLICATIONS

Executive Summary

64 pages
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Overview of Key Messages from the WWDR4

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Facts and Figures from the WWDR4

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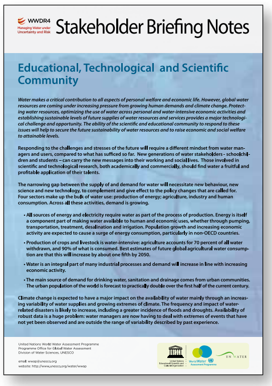

Stakeholder Messages from the WWDR4

Targetted to various audiences:

1. Educational, technological and scientific community
2. International finance institutions and commercial financiers
3. Water service providers (utilities and companies)
4. Central government (ministers, politicians and senior officials) and local government mayors and officials
5. Lay public, civil society and faith leaders
6. Donors and development NGOs
7. Business community

2 pages each
Available in English

United Nations
Educational, Scientific and
Cultural Organization

World Water
Assessment Programme

UN WATER

WWDR4

UN WATER Reports

UN-Water is the United Nations (UN) inter-agency coordination mechanism for freshwater-related issues, including sanitation. It was formally established in 2003 building on a long history of collaboration in the UN family. UN-Water is comprised of UN entities with a focus on, or interest in, water-related issues as Members and other non-UN international organizations as Partners.

The work of UN-Water is organized around Thematic Priority Areas and Task Forces as well as awareness-raising campaigns such as World Water Day (22 March) and World Toilet Day (19 November).

The main purpose of UN-Water is to complement and add value to existing programmes and projects by facilitating synergies and joint efforts, so as to maximize system-wide coordinated action and coherence. By doing so, UN-Water seeks to increase the effectiveness of the support provided to Member States in their efforts towards achieving international agreements on water.

PERIODIC REPORTS

World Water Development Report (WWDR)

is the reference publication of the UN system on the status of the freshwater resource. The Report is the result of the strong collaboration among UN-Water Members and Partners and it represents the coherent and integrated response of the UN system to freshwater-related issues and emerging challenges. The Report's production is coordinated by the World Water Assessment Programme and the theme is harmonized with the theme of World Water Day (22 March). From 2003 to 2012, the WWDR was released every three years and from 2014 the Report is released annually to provide the most up to date and factual information of how water-related challenges are addressed around the world.

- ✓ Strategic outlook
- ✓ State, uses and management of water resources
- ✓ Global
- ✓ Regional assessments
- ✓ Triennial (2003–2012)
- ✓ Annual (from 2014)
- ✓ Links to the theme of World Water Day (22 March)

Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS)

is produced by the World Health Organization (WHO) on behalf of UN-Water. It provides a global update on the policy frameworks, institutional arrangements, human resource base, and international and national finance streams in support of sanitation and drinking water. It is a substantive input into the activities of Sanitation and Water for All (SWA).

- ✓ Strategic outlook
- ✓ Water supply and sanitation
- ✓ Global
- ✓ Regional assessments
- ✓ Biennial (since 2008)

The progress report of the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP)

is affiliated with UN-Water and presents the results of the global monitoring of progress towards MDG 7 target C: to halve, by 2015, the proportion of the population without sustainable access to safe drinking-water and basic sanitation. Monitoring draws on the findings of household surveys and censuses usually supported by national statistics bureaus in accordance with international criteria.

- ✓ Status and trends
- ✓ Water supply and sanitation
- ✓ Global
- ✓ Regional and national assessments
- ✓ Biennial (1990–2012)
- ✓ Annual updates (since 2013)

UN-WATER PLANNED PUBLICATIONS 2014–2015

- UN-Water Technical Advice on a Possible Post-2015 Global Goal for Water
- UN-Water Analytical Brief on Wastewater Management
- UN-Water Report on the International Year of Water Cooperation
- UN-Water Report on the International Decade for Action 'Water for Life' 2005–2015
- UN-Water Country Briefs
- UN-Water Policy Brief on Discrimination and the Right to Water and Sanitation
- UN-Water Policy Brief on Water Security

More information on UN-Water Reports at: http://www.unwater.org/publications

WWDR 2014

The United Nations World Water Assessment Programme (WWAP) is hosted and led by UNESCO and brings together the work of 31 UN-Water Members as well as 34 Partners in the United Nations *World Water Development Report* (WWDR) series.

The WWDR 2014 marks the transition of the series to an annual publication cycle with a theme for each year – 'Water and Energy' for 2014. This edition of the Report seeks to inform decision-makers within and beyond the water–energy nexus about the interconnections and interdependencies between water and energy; the inevitable trade-offs experienced when providing water and energy for basic human needs and to support sustainable development; and the need for appropriate responses that account for both water and energy priorities, particularly in the context of post-2015 targets on increasing access to water and energy. It provides a detailed overview of major and emerging trends from around the world, with examples of how some of these have been addressed and the implications for policy-makers, and actions that can be taken by various stakeholders and the international community.

Like the earlier editions, the WWDR 2014 contains country-level case studies describing the progress made in meeting water- and energy-related objectives. This edition also presents a Data and Indicators Annex of 41 indicators, which benchmark actual conditions and highlight trends related to water and energy around the world.

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