Institut de Ciència i Tecnologia Ambientals

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Energy for Sustainable Development – An Assessment of the Energy-Poverty-Development Nexus

Doctoral Thesis

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Summary

Energy is central to many aspects of socio-economic emancipation. The services that most people in industrialised countries take from granted – adequate lighting, low-polluting heating and cooking energy, telecommunication and entertainment, motive power – are out of reach to large parts of the world's population. A lack of access to affordable and reliable energy services represents a key obstacle to human, social, and economic development and the achievement of the Millennium Development Goals. As unacceptable and unsustainable as it is, widespread energy poverty represents a stark reality which must be dealt alongside other pressing global issues.

Despite the significant efforts by local institutions and governments, utilities and international organisations, the absolute number of energy poor is expected to rise in coming decades in the absence of additional dedicated action. History has shown, however, that significant progress can be achieved with regard to improving energy access in a short timeframe. Remarkable improvements occurred rapidly in several Asian countries (e.g. Vietnam), South Africa and Brazil in the recent past. However, current initiatives to eradicate energy poverty are insufficient in scale and scope, and attempting to address the issue in the same incremental fashion as in the past is clearly inappropriate.

Energy for development strategies must go well beyond merely providing light to poor households. They should aim at transformative changes that bring about sustainable development. The recent succession of crises has set back some development progress. The international community needs to adjust swiftly to the new circumstances and provide advice and assistance that is resilient and long-lasting, and creates an environment that is conducive to enhancing endogenous development. Today, there is no technical barrier to providing the billions of energy poor with modern, safe, reliable and affordable energy services. It is our duty to deal with the aspiration of countries to move towards modern economies, and energy is paramount to such transformation.

Fortunately, the issue of energy access is receiving greater and greater attention. As an illustrative example, 2012 has been declared by the General Assembly, the main deliberative, policymaking and representative organ of the United Nations, as the *International Year of Sustainable Energy for All*. It is crucial to capitalise on this momentum, as energy is central to facing many of today's key development challenges. Addressing the issue of energy poverty in a comprehensive manner would have enormous multiple benefits (e.g. health, education, gender equality).

The various chapters of this thesis form a coherent ensemble of individual pieces of analysis around a core topic, namely the nexus between energy and socio-economic development. The different chapters, which are based on stand-alone articles, provide contrasting and complementary perspectives around the issue at hand. It consists of applied research as well as methodological development, and forms altogether an integrated assessment of energy for sustainable development.

The thesis is organised in such a way so as to present a consistent and structured narrative. In terms of broad structure, the first chapters gauge the issue of energy poverty, or the lack of access to modern energy services. They offer a sense of the magnitude of the challenge at hand, as well as present an assessment of scenarios towards universal energy access. This is followed by insights on the scale of investment required to address the issue. Finally, concrete interventions to overcome some of the issues are discussed.

Energy and the Millennium Development Goals

While intuitive, the relationship between energy and development is difficult to quantitatively ascertain and has not been analytically explored in detail in the scientific literature. The correlation between access to energy services and development is, however, often addressed in aggregate in the literature, for example by using composite indexes such as the Human Development Index (HDI), or by focusing strictly on economic impacts. This analysis presents a statistical articulation of the link between energy and various proxies of development, using the Millennium Development Goals as a framework. The outcomes confirm the potentially positive influence of access to energy services on development. The assessment provides a perspective on a number of often employed assumptions

about the correlation between energy and development, and challenges claims of its universally positive benefits to specific development priorities. It is found that the benefits to development of access to energy services vary considerably.

Measuring Energy Poverty

Effective policies to dramatically expand modern energy access need to be grounded in a robust information-base. Metrics that can be used for comparative purposes and to track progress towards targets therefore represent an essential support tool. This analysis reviews the relevant literature, and discusses the adequacy and applicability of existing instruments to measure energy poverty. Drawing on those insights, it proposes a new composite index to measure energy poverty. Both the associated methodology and initial results for several African countries are discussed. Whereas most existing indicators and composite indices focus on assessing the access to energy, or the degree of development related to energy, the new index developed – the Multidimensional Energy Poverty Index (MEPI) – focuses on the deprivation of access to modern energy services. It captures both the incidence and intensity of energy poverty, and provides a new tool to support policy-making.

Energy Access Scenarios to 2030 for sub-Saharan Africa

In order to reach a goal of universal access to modern energy services by 2030, consideration of various electricity sector pathways is required to help inform policy-makers and investors, and help guide power system design. To that end, and building on existing tools and analysis, several 'high-level', transparent, and economy-wide scenarios for the sub-Saharan African power sector to 2030 are presented. These simple scenarios are constructed against the backdrop of historical trends and various interpretations of universal access. They are designed to provide the international community with an indication of the overall scale of the effort required. Most existing projections, using typical long-term forecasting methods for power planning, show roughly a threefold increase in installed generation capacity occurring by 2030, but more than a tenfold increase would likely be required to provide for full access – even at relatively modest levels of electricity consumption. This equates to approximately a 13% average annual growth rate, compared to a historical one (in the last two decades) of 1.7%.

Scale of Investment for Universal Energy Access

To help provide clarity, support political decision making, and inform the design of financial responses, the overall scale of spending required to meet universal access to modern energy services is considered. The existing literature at the global, regional, national, and project levels and disaggregate cost estimates is reviewed in order to provide increased transparency through comparable metrics. A new methodology is developed to calculate three new cost scenarios that attempt to address several existing analytical gaps. As a conclusion, the total cost of providing (near) universal access is expected to be likely considerably higher than published estimates which often focus primarily on capital costs. While recognizing the coarse nature of the analysis, the annual cost of universal access to electricity and clean cooking is estimated at ranging from USD 14 to 136 billion (USD 12 - 134 billion for electrification and USD 1.4 to 2.2 billion for clean cooking) depending on the various scenarios and assumptions.

Current Financial Flows related to Energy Access

To help inform the design of appropriate and effective policies to reduce energy poverty, this analysis presents an assessment of the current macro financial flows in the electricity and gas distribution sectors in developing countries. It builds on the methodology used to quantify the flows of investment in the climate change area. The approach relies on national gross fixed capital formation, overseas development assistance, and foreign direct investment. These high-level and aggregated investment figures provide a sense of the scale to policy-makers, but are only a small part of the information required to design financial vehicles. In addition, these figures tend to mask numerous variations between sectors and countries, as well as trends and other temporal fluctuations. Nonetheless, for the poorest countries, one can conclude that the current flows are considerably short (at least five times) of what will be required to provide a basic level of access to clean, modern energy services to the 'energy poor'.

Clean Development Mechanism and Sustainable Development

The Clean Development Mechanism (CDM) has a twofold objective, to offset greenhouse gas emissions and to contribute to sustainable development in the host country. The contribution to the latter objective seems marginal in most CDM activities. Also, CDM activities are unevenly spread among developing countries. In response to these concerns, initiatives with the objective of promoting CDM projects with broad local sustainable development dividends have been launched, such as the Gold Standard and the Community Development Carbon Fund. The Gold Standard label rewards best-practice CDM projects while the Community Development Carbon Fund focuses on promoting CDM activities in underprivileged communities. Using a multi-criteria method, the potential contribution to local sustainable development of those CDM projects with particular attributes is compared with ordinary ones. This evaluation suggests that labelled CDM activities tend to slightly outperform comparable projects, although not unequivocally.

Resumen

La energía es un elemento fundamental para muchos aspectos del desarrollo socioeconómico. Los servicios que la mayoría de las personas en los países industrializados dan garantizados - iluminación adecuada, energía limpia para calefacción y cocina, telecomunicaciones, fuerza motriz y ocio - están fuera del alcance en gran parte de la población mundial. La falta de acceso a servicios energéticos confiables y asequibles representa un claro obstáculo para el desarrollo humano, social, económico y para el logro de los Objetivos de Desarrollo del Milenio. Constituyendo actualmente un hecho inaceptable e insostenible, la pobreza energética representa una cruda realidad que junto a otros problemas globales debe ser tratada de manera urgente.

A pesar de los importantes esfuerzos realizados por las instituciones y los gobiernos locales, las entidades públicas y las organizaciones internacionales, la tendencia indica que el número total de pobres en términos de acceso a la energía aumente en las próximas décadas, a menos de que se inicien de forma inmediata acciones adicionales orientadas a evitar ese incremento. En este sentido, la historia ha demostrado que es posible lograr un significativo avance en acceso energetico en un corto espacio de tiempo. Este hecho se ha producido recientemente en varios países asiáticos (por ejemplo, Vietnam), Sudáfrica y Brasil. Sin embargo, a pesar de los avances realizados en los países mencionados, las iniciativas que hoy en día se están desarrollando a nivel global para erradicar la pobreza energética no son suficientes en cuanto a su tamaño y alcance.

Las estrategias relacionadas con la promoción del acceso a la energía para el desarrollo socioeconómico deben ir mucho más allá de la iluminación para hogares pobres. Los objetivos de dichas estrategias deberían estar orientados a generar cambios estructurales que originen un desarrollo sostenible. Además, la reciente crisis ha provocado retrocesos en el desarrollo sostenible de los países. La comunidad internacional tiene que adaptarse rápidamente a las nuevas circunstancias y proporcionar asesoramiento y asistencia que sea duradera en el tiempo y adaptable a cada caso, de cara a provocar un ambiente propicio para el desarrollo interno en los países. Hoy en día, no existen barreras técnicas que impidan suministrar servicios modernos de energía de forma segura, fiable y asequible a los miles de millones de pobres que no tienen acceso a la misma. Es nuestro deber contribuir a lograr la aspiración de los países más desfavorecidos para avanzar hacia economías sostenibles, y la energía es fundamental para esta transformación.

Afortunadamente, el tema de acceso a la energía está recibiendo una atención cada vez mayor en todas las esferas. Como ejemplo ilustrativo de este hecho, el año 2012 ha sido declarado por la Asamblea General, el principal órgano normativo y representativo de las Naciones Unidas, como el Año Internacional de la Energía Sostenible para Todos. Es fundamental aprovechar este impulso, ya que la energía es necesaria para enfrentar muchos de los desafíos clave actuales. Así, abordar la pobreza energética de manera integral tendría enormes beneficios en diversas áreas relacionadas con el desarrollo de los países (por ejemplo, salud, educación, igualdad de género).

Los capítulos de esta tesis persiguen conformar un conjunto coherente de piezas individuales de análisis en torno a un tema central: el nexo entre energía y el desarrollo socio-económico. Los diferentes capítulos están basados en artículos independientes y ofrecen perspectivas contrastadas y a la vez complementarias en relación al tema en cuestión. En definitiva, se trata de un ejercicio de investigación aplicada así como de desarrollo metodológico y el conjunto deriva en una evaluación integrada de las implicaciones de la energía para el desarrollo sostenible.

La tesis está organizada de forma que se presente como una narrativa coherente y estructurada. En términos generales de su estructura, los primeros capítulos describen el problema de la pobreza energética, como la falta de acceso a servicios energéticos modernos. Estos capítulos ofrecen una idea de la magnitud del desafío que nos ocupa y presentan una evaluación de los escenarios posibles para lograr el acceso universal a la energía. En los capítulos siguientes, se presenta la escala de la inversión necesaria para abordar la cuestión así como intervenciones concretas que permitirían superar algunas de las cuestiones que se discuten.

La Energía y los Objetivos de Desarrollo del Milenio

Aunque intuitiva, la relación entre energía y desarrollo sostenible es difícil de determinar cuantitativamente y no ha sido explorada ni analizada en detalle en la literatura científica. La correlación entre el acceso a los servicios de energía y el desarrollo socioeconómico se refleja a menudo, por ejemplo, mediante el uso de índices compuestos como el Índice de Desarrollo Humano (HDI), o a partir de un análisis centrado únicamente en las repercusiones económicas. Este trabajo presenta una articulación estadística que analiza la relación entre la energía y varios elementos clave del desarrollo socioeconómico, utilizando los Objetivos de Desarrollo del Milenio como marco de referencia. Los resultados confirman la influencia potencialmente positiva que el acceso a los servicios de energía genera. La evaluación desarrollada en el trabajo proporciona una perspectiva basada en una serie de supuestos que a menudo se emplean alrededor de la correlación entre energía y desarrollo, y examina reivindicaciones de sus beneficios universalmente positivos a las prioridades específicas de desarrollo socioeconómico. Entre las conclusiones, se destaca que los beneficios para el desarrollo sostenible del acceso a los servicios de energía varían considerablemente.

Medición de la pobreza energética

Cualquier política que pretenda ser efectiva para expandir de forma considerable el acceso a energía moderna ha de estar fundamentada en una sólida base documental. Por lo tanto los análisis cuantitativos que se pueden utilizar con fines comparativos y de seguimiento de los avances hacia los objetivos planteados, representan una herramienta de apoyo esencial. Este trabajo revisa la literatura relevante en la materia, y analiza la idoneidad y la aplicabilidad de los instrumentos existentes para medir la pobreza energética. Basándose en esos instrumentos y en sus resultados, se propone un nuevo índice compuesto para medir la pobreza energética. Tanto la metodología como los resultados iniciales obtenidos de la aplicación del índice son presentados para varios países africanos. Mientras que la mayoría de los indicadores e índices compuestos existentes se centran en la evaluación del acceso a la energía o en el grado de desarrollo relacionado con la energía, el nuevo índice desarrollado - el Índice de Pobreza Multidimensional de la Energía (MEPI) - se centra en la privación del acceso a servicios energéticos modernos. Este índice, refleja la incidencia e intensidad de la pobreza energética y proporciona una nueva herramienta para la elaboración de políticas.

Escenarios de acceso a la energía hasta el año 2030 para el África subsahariana

Con el fin de alcanzar una meta de acceso universal a servicios modernos de energía para el año 2030, se han considerado varias opciones de desarrollo de sector eléctrico así como el hecho de informar consecuentemente a los políticos e inversionistas, de cara a orientar de forma adecuada el diseño del sistema. Con este fin, y basándose en las herramientas y análisis existentes, se presentan varios escenarios de forma transparente y para toda la economía del sector energético de África subsahariana hasta el año 2030. Estos escenarios se han elaborado teniendo en cuenta el contexto de las tendencias históricas y las diversas interpretaciones sobre el concepto de acceso universal a la energía. Los mismos, están diseñados para proporcionar una indicación de la escala general en relación al esfuerzo requerido por la comunidad internacional. Actualmente, la mayoría de las proyecciones con métodos tradicionales de predicción a largo plazo en materia de planificación energética muestran un aumento de aproximadamente tres veces la capacidad de generación instalada para el año 2030, pero probablemente se requiera que ese aumento sea de más de diez veces, si se pretende proporcionar un acceso completo a nivel global - incluso a niveles relativamente modestos de consumo de electricidad. Esto equivale a aproximadamente un 13% la tasa media de crecimiento anual, en comparación con un histórico (en las últimas dos décadas) de 1,7%.

Escala de la inversión para el acceso a la energía universal

Para ayudar a proporcionar una mayor claridad y apoyo a la toma de decisiones políticas, así como en el diseño de propuestas financieras, en este trabajo es considerado y analizado el nivel global de gasto requerido para satisfacer el acceso universal a servicios de energía modernos. Este trabajo revisa la literatura existente a nivel mundial, regional, nacional y de proyecto, y a su vez se realiza un desglose de las estimaciones de costos necesarios, a fin de proporcionar una mayor transparencia a través del desarrollo de indicadores comparables. Con la nueva metodología desarrollada, calculamos tres escenarios de costos nuevos que intentan abordar varias deficiencias analíticas existentes. Como conclusión, el costo total de proporcionar (de forma aproximada) el acceso universal se espera que probablemente sea considerablemente más alto que las estimaciones publicadas, que a menudo se centran principalmente en los costos de capital. Si bien se reconoce la naturaleza aproximada de los análisis, el costo anual del acceso universal a la electricidad y energía limpia para la cocinar se calcula que va desde USD 14 a 136 mil millones (de USD 12 a 134 mil millones para electrificación y de USD 1,4 a 2,2 mil millones para energía limpia para la cocinar).

Actuales flujos financieros relacionados con el acceso a la energía

De cara a contribuir al diseño de políticas apropiadas y eficaces para reducir la pobreza energética, este análisis presenta una evaluación de los flujos macro financieros actuales en el sector eléctrico y de distribución de gas en los países en desarrollo. Se basa en la metodología más extendida actualmente para cuantificar los flujos de inversión en el área de cambio climático. El enfoque se centra en las variables de formación bruta de capital fijo nacional, la ayuda al desarrollo procedente del extranjero y la inversión extranjera directa. Estas cifras proporcionan a los responsables políticos una idea de la escala de inversión necesaria, aunque esto representan sólo una pequeña parte de la información necesaria para diseñar los instrumentos financieros requeridos para lograr el acceso universal a la energía. Igualmente, estas cifras tienden a ocultar muchas variaciones entre sectores y países, así como las tendencias y otras fluctuaciones en el tiempo. En cualquier caso, se puede concluir que la corriente de inversión destinada a los países más pobres se queda muy corta (por lo menos cinco veces) si se pretende proporcionar un nivel básico de acceso a servicios modernos de energía limpia a los 'pobres energéticos'.

Mecanismo de Desarrollo Limpio y el Desarrollo Sostenible

El Mecanismo de Desarrollo Limpio (MDL) tiene un doble objetivo: compensar las emisiones de gases de efecto invernadero y contribuir al desarrollo sostenible en el país anfitrión, aunque la contribución a este último objetivo parece marginal en la mayoría de las actividades del MDL. Además, las actividades del MDL están distribuidas de forma desigual entre los países en desarrollo. En respuesta a estas inquietudes, se han puesto en marcha varias iniciativas cuyo objetivo es la promoción de proyectos MDL que generen amplios dividendos orientados al desarrollo local sostenible, como el Gold Standard y el Community Development Carbon Fund (CDCF). La certificación Gold Standard recompensa las mejores prácticas de proyectos MDL, mientras que el CDCF se centra en la promoción de las actividades del MDL en comunidades desfavorecidas. A partir de un método de criterios múltiples, este trabajo analiza, la contribución potencial al desarrollo local sostenible de los proyectos del MDL, comparando los proyectos que tienen atributos particulares con los proyectos ordinarios. Los resultados obtenidos sugieren que generalmente aunque no siempre, los proyectos MDL con certificación, tienden a superar ligeramente a los proyectos similares sin certificación en términos de beneficios a nivel local.

List of Acronyms

ADAM	Adaptation and Mitigation Strategies (project)
AGECC	Advisory Group on Energy and Climate Change (to the UN Secretary-General)
AICD	Africa Infrastructure Country Diagnostic
ASER	Agence Sénégalaise d'Electrification Rurale
BASE	Basel Agency for Sustainable Energy
BNEF	Bloomberg New Energy Finance
BP	British Petroleum
CDCF	Community Development Carbon Fund
CDM	Clean Development Mechanism
CEMAC	Commission de la Communauté Economique et Monétaire de l'Afrique Centrale
CER	Certified Emission Reductions
CFL	Compact Fluorescent Lamp
CO_2	Carbon dioxide
CREAF	Centre de Recerca Ecològica i Aplicacions Forestals
CRS	Creditor Reporting System
CSD	Commission on Sustainable Development (United Nations)
DFID	Department for International Development (UK aid)
DHS	Demographic and Health Surveys
DNA	Designated National Authority
EAC	East African Community
EAPP	East Africa Power Pool
ECOWAS	Economic Community Of West African States
EDI	Energy Development Index
EIA	Energy Information Administration (United States)
EIA	Environmental Impact Assessment
EISD	Energy Indicators for Sustainable Development
EROI	Energy Return On Energy Input
ESMAP	Energy Sector Management Assistance Program
EU	European Union
FAO	Food and Agriculture Organization
FDI	Foreign Direct Investments
FEMA	Forum of Energy Ministers in Africa
GDP	Gross Domestic Product
GEA	Global Energy Assessment

GEF	Global Environment Facility
GFCF	Gross Fixed Capital Formation
GHG	Greenhouse Gas
GNESD	Global Network on Energy for Sustainable Development
GTZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HANPP	Human Appropriation of Net Primary Production
HDI	Human Development Index
HFC	Hydrofluorocarbon
HWWA	Hamburgisches Welt-Wirtschafts-Archiv
IAEA	International Atomic Energy Agency
ICTA	Institut de Ciència i Tecnologia Ambientals
IEA	International Energy Agency
IEO	International Energy Outlook
IIASA	International Institute for Applied Systems Analysis
IISD	International Institute for Sustainable Development
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
IUCN	International Union for Conservation of Nature
JI	Joint Implementation
JPOI	Johannesburg Plan of Implementation
LDC	Least Developed Country
LPG	Liquefied Petroleum Gas
MATA-CDM	Multi-Attributive Assessment of CDM
MAUT	Multi-Attributive Utility Theory
MCA	Multi-Criteria Assessment
MDG	Millennium Development Goal
MDL	Mecanismo de Desarrollo Limpio
MEPI	Multidimensional Energy Poverty Index
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental impact
MPI	Multidimensional Poverty Index
NASA	National Aeronautics and Space Administration
NEPAD	New Partnership for Africa's Development
O&M	Operation and Maintenance
ODA	Official Development Assistance

ODF	Official Development Finance
OECD	Organisation for Economic Co-operation and Development
OPHI	Oxford Poverty and Human Development Initiative
OSL	Ordinary Least Square
PDD	Project Design Document
PIDA	Study on Programme for Infrastructure Development in Africa
PPI	Private Participation in Infrastructure
PPM	Part per million
PPP	Purchasing Power Parity
PPP	Public Private Partnership
PROMETHEE	Preference Ranking Organisation METHod for Enrichment Evaluations
PV	Photovoltaics
REEEP	Renewable Energy and Energy Efficiency Partnership
RSA	Republic of South Africa
SADC	Southern African Development Community
SAPP	Southern African Power Pool
SEI	Stockholm Environment Institute
SHP	Small Hydropower
SSA	Sub-Saharan Africa
T&D	Transmission and Distribution
UAB	Universitat Autònoma de Barcelona
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNF	United Nations Foundation
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
UNIDO	United Nations Industrial Development Organization
UNSD/ UNSTAT	United Nations Statistics Division
USAID	United States Agency for International Development
USD	United States Dollar
WAPP	West Africa Power Pool
WB	World Bank
WCED	World Commission on Environment and Development

WEF	World Economic Forum
WEO	World Energy Outlook
WHO	World Health Organization
WSSD	World Summit on Sustainable Development

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Preface and acknowledgement

I was initially trained as mechanical engineer with a specialisation in energy systems at the University of Applied Sciences of Western Switzerland in Yverdon. After a few years working in the private sector for a multinational corporation in the energy sector, my keen interest in environmental and developmental issues was a trigger to take up post-graduate level study in the field at the *Institut de Ciència i Tecnologia Ambientals* (ICTA) of the *Universitat Autònoma de Barcelona* (UAB). Following the completion of my Masters degree I decided to pursue a PhD. By this stage, I worked as Research Assistant at the International Institute for Applied Systems Analysis on the Global Energy Assessment, which is a major, multi-year initiative to assess the global energy challenges. My current position is with the United Nations Industrial Development Organization (UNIDO) where I develop and implement energy and environment related technical cooperation projects.

Photos courtesy for the cover page: Peter DiCampo.

A number of individuals have been instrumental to my intellectual development and the shaping of this Thesis in the various institutions where I have studied and worked in the recent years. I am most grateful to my Thesis Director, Joan Martínez Alier, an ecological economist from the ICTA of the UAB. Professor Martínez Alier provided me with crucial guidance, substantive input, and encouragement during the past few years. The co-supervisor of my Thesis, Anthony Patt, a senior research scholar at IIASA, offered intellectual support and advice in a number of occasions. I am thankful for that most valuable input and backing.

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I am also grateful to John Holmes, my father-in-law, for proof-reading sections of this Thesis and providing general advice and support during my post-graduate studies.

Finally, this Thesis would have been impossible without the relentless support of my family, particularly from Victoria my wife. There are no words to express how appreciative I am. This work is dedicated to her and our two sons, Callum and Damien.

Disclaimer

1. Introduction

A fortunate fraction of the word's population has reached unprecedented level of welfare. Never before have so many people enjoyed a long, healthy and fulfilling life. Most human development indicators, ranging from life expectancy to education and from wealth to social integration, are on a steady rising trend. Relatively rapid improvements in terms of wellbeing are achievable, as empirical evidences demonstrate. Since the advent of the industrial revolution, at the centre of this progress is the availability of relatively inexpensive energy.

This notwithstanding, a significant share of human beings has not benefited, or has benefited to a lesser extent, from those remarkable improvements in quality of life. Whilst great progress has been made in alleviating poverty in a number of contexts, a considerable proportion of people remain desperately poor, enduring abject living conditions with limited prospect of improvement. For those, the lack of access to modern energy services represents a huge burden.

Beside being an engine for socio-economic development, energy is at the centre of most major contemporary challenges. Today's environmental degradation, including the anthropogenic interference with the climate system, is unparalleled in human history. Modern economies strive on the availability of an adequate and secure supply of energy. Nonetheless, operating energy systems, particularly large-scale ones, involve ancillary or substantial risks (e.g. oil spills, nuclear accidents) that need to be contained. Traditional mechanisms, such as insurance systems for example, have proved inadequate in some instances to bring risk routinely into everyday management of private and public business, as it happens, say, with car accidents.

Meeting the energy service needs and realizing the aspirations of the poor and rich, in conjunction with the need to preserve ecosystems, will require nothing short of a paradigm shift with regard to the way we transform and use energy. Along those lines, Costanza (1997) argues for the need to switch from quantitative development to a qualitative evolution. Current patterns of socio-economic development are clearly unsustainable, and the need for a shift towards a development paradigm that is more sustainable is stronger than ever before.

The following subsections frame this Thesis and provide contextual background. Section 1.5 provides an overview about the structure of the core of the Thesis.

1.1. Framing and rationale

The elements of this Thesis present various, yet coherent, perspectives on the multifaceted, complex relationship between energy and development, in line with the notion of integrated assessment. Indeed, congruent with well-established descriptions (Rotmans & Asselt 1996; van der Sluijs 2002) of the concept of integrated assessment, this work attempts to combine, interpret and communicate knowledge from various domains to synthesize information that cannot be distilled from a single disciplinary analysis, with the objective of deriving a synoptic view of the issue at hand.

1.1.1. Theoretical inspiration: ecological economics and science for policy

The research presented in this Thesis has been influenced and informed by a range of schools of thoughts. The following paragraphs briefly capture, non-exhaustively, the essence of those academic inspirations.

Ecological economics, an academic field which is transdisciplinary[1] in nature, deals with the interaction between humans and the ecosystems. Costanza et al. (1997) describes ecological economics as reposing on a small set of main pillars:

[1] In the ecological economics vision, the boundaries between disciplines have been completely eliminated and the problems and questions are seen as a seamless whole in an intellectual landscape that is also changing and growing (Costanza 1997).

- A vision of the earth that is thermodynamically closed (i.e, open to the entry of sun energy and almost totally closed to the entry of materials);
- The future vision of a sustainable planet with a high quality of life for both humans and other species within given material constraints;
- The recognition that in the analysis of complex systems like the earth at all space and time scales, fundamental uncertainty is large and irreducible and certain processes are irreversible, requiring a fundamentally precautionary stance; and
- That institutions and management should be proactive rather than reactive and should result in simple, adaptive, and implementable policies based on a sophisticated understanding of the underlying systems which fully acknowledges the underlying uncertainties. This forms the basis for policy implementation which is itself sustainable.

As a main divergence to environmental economics, ecological economists emphasise *strong* sustainability and reject the proposition that natural capital can be substituted without limit by human-made capital. In terms of operationalisation, the environmental economists apply an economic value to a stock of capital whilst ecological economists refer to it in its respective physical units (Rifkin 2011). This perspective is described for instance in a seminal paper by Funtowicz & Ravetz (1994) quite appropriately entitled 'The worth of a songbird'.

With regard to sustainable development assessment, there is often no common metric with which a criterion can be evaluated against another one (as illustrative example: comparing the number of jobs created/lost with the impact on natural resources). However, this does not imply incomparability, but rather that the comparison across the values should preferably be performed without the use of a single type of measure. Multi-criteria theory proposes a range of methodological tools that allow dealing with the incommensurability of values (Martinez-Alier, Munda & O'Neill 1998).

Multi-criteria as an approach doesn't solve all the issues related to the evaluation of multifaceted issues, nor does it reduce the uncertainty linked to such assessment. Nevertheless, it assists in structuring the problem and allows for a clear and transparent appraisal and therefore has a clear advantage over informal judgments. Those techniques help to deal with complexity by establishing preferences between alternatives to serve a predefined objective. Multi-criteria theory provides a framework for applied social choices (Munda 2008).

The concepts of complex system and post-normal science have also inspired the various analyses in terms of the conceptualisation of the problem at hand and the methodological choices to assess those. Those schools of thoughts assume as a point of departure that there need not necessarily be rational and objective answer to most questions (Strand 2002). As Latour (1997) describes, the organisation of our society does not work on the clear division between natural and cultural aspects. Wynne (1992) points out that scientific knowledge isn't purely objective. The investigator as well as the different actors have they own roles within the system.

A common denominator between the pieces of analysis presented herein and post-normal science lies in their objective: to provide transparent scientific information to inform policy decisions. The circumstances to carry out science for policy are quite different to those for pure science. In the words of Thomas Kuhn, the latter involves puzzle-solving normal science within a paradigm that ensures the steady accumulation of relatively stable and certain facts, employing recognised methods (Kuhn 1970).

On the other hand, uncertainty, which is irreducible in many instances, and value issues are intrinsic to the realm of science for policy. As eloquently put by Funtowicz and Ravetz (1993), many facts and consequences are uncertain, some of the values are in dispute, the stakes are high, and thus the need for decisions and action is urgent. Therefore, characteristic to this type of analysis is the need not to assume that the cognitive elements can be isolated from the values.

Another line of thinking which significantly influenced the work presented in this Thesis is that related to the concept of 'Development as Freedom' as persuasively described by Amartya Sen. Under this theory, escaping from poverty is a matter of realising ones' capabilities, as opposed to the more materialistic approach of prevalent development theory. Instrumental freedoms (political freedoms, economic facilities, social opportunities, transparency guarantees, and protective security), Sen (1999) argues, constitute not only the means but also the ends in development. Under those terms, energy, as well as other commodities, represents mere means to achieve 'higher' goals.

1.1.2. Scope and definitions: energy and energy services

Energy is at the heart of social and economic development. This is a point that energy analysts and human ecologists have made for a long time, since Lotka and Ostwald in the 1910s to H.T. Odum in the 1970s and Robert Ayres and others today (see e.g., Ayres and Warr 2005; Warr and Ayres 2010, 2012; Warr et al. 2010). Economic growth goes together with increasing inputs of energy in terms of work done.

Lotka (1956) introduced a basic distinction in human ecology between the endosomatic use and the exosomatic use of energy. The first refers to food consumption. On average, a person needs about 1800 kcal per day as a minimum energy intake[2]. It is convenient to remember that 2400 kcal equals 10 MJ. Therefore a well fed human's endosomatic use of energy is about 3.65 GJ per year. The exosomatic use of energy can be only twice as much (for basic energy services) for a very poor person, or it can be one hundred times as much for an average western citizen.

In this Thesis the focus is on exosomatic energy use, whether obtained commercially or directly secured from forests or fields, exclusively. The ability of a physical system to do work on another physical system is what is referred to in this Thesis with the notion of energy. The energy flows needed to sustain life of living organisms in terms of food and fodder are not considered in the analyses presented in this Thesis.

The notion of energy services refers to the utility of energy, or the application of useful energy to tasks desired by the consumer such as transportation, a warm room, or light. The concept of 'modern' energy services is to be understood as those energy services that are rendered through the use of energy sources that are other than so-called traditional (e.g. fuelwood, animal dung, shrub and grass). Energy poverty refers to the lack of access to reliable and affordable modern energy services, be it partial or full.

1.1.3. Analytical gaps in the study of energy for sustainable development

In order to go beyond the cliché that energy is necessary for development, this nexus deserves close scrutiny. Energy represents a defining element of our time, as well as that of future generations. The interrelationship between energy and socio-economic development is at the very core of this Thesis. A detailed understanding of this interrelation is crucial for devising measures and policies to overcome related global issues.

The issue of energy poverty is not new. Neither are the means to deal with it. But without dedicated action, the situation is likely to stagnate at best, and worsen in some cases; the number of people suffering from the lack of access to electricity is expected to rise in absolute terms in some regions, notably sub-Saharan Africa (IEA, UNDP & UNIDO 2010). The obstacles to widespread energy access are well known, and not insurmountable.

Analysis in the field of energy poverty is commonly constrained by data paucity. Indeed, the information base in terms of quantitative and qualitative data is patchy at best. Designing and implementing strategies to make energy poverty history in the foreseeable future requires input that go beyond abstraction.

Careful analysis to inform the design of measures and policies, as well as the development of technical cooperation programmes and projects, is of crucial importance to address the issue of energy poverty. Evidence-based research provides a sound basis for grounding dedicated action in the field. Whilst significant work has been produced on the topic, important analytical gaps remain. The pieces of

[2] Based on FAO data; see http://www.fao.org/hunger/en/.

research presented in this Thesis each contribute to the body of knowledge related to the realm of energy for sustainable development.

1.2. Energy for sustainable development – challenges and opportunities

This section briefly reviews past and future trends on major energy-related contemporary challenges by way of substantively setting the scene of this Thesis and providing it with context and justification.

A number of interrelated aspects are to be considered when looking at the energy-poverty-development nexus, including notably persistent poverty and inequality, the lack of access to modern energy services (energy poverty), climate change and sustainable development. There are numerous other important issues, such as energy security, and other forms of environmental damages. There is a rich literature discussing those specific issues, as well as their interlinkages, as in, for example, the Global Energy Assessment[3].

1.2.1. Sustainability and sustainable development

There was a clear shift a few decades ago in the environmentalist movements. The idea that environmental conservation does not stand in opposition to development (IUCN, UNEP & WWF 1991) had been first brought up in the early 1980s, thereby also acknowledging that the consequence of poverty and misery can be a burden to the environment. The need for people to enjoy a life of dignity, combined with conservation arguments, gave birth to the concept of sustainable development.

In order to assess sustainability, it is appropriate to review the different perspectives about and understandings of the concept. There is no single definition of sustainability. Its meaning is strongly dependent on one's approach to environmental management. Also, its interpretation varies depending on different assumptions in regards to human nature, society at large as well as the interaction between society and nature (Özkaynak, Devine & Rigby 2004), which in turn deeply influence its operationalisation.

The polyvalence of the concept of sustainability varies in relation to different social groups and practices, their particular beliefs, values or interests (Tàbara 2002). Despite the absence of a unanimously recognised definition, the notion is far from being futile and has represented the foundation of policy formulation in the recent years.

One could argue that sustainability is a relatively hypothetical state compared to the current way-of-life, especially in the western world. The concept of sustainability can be interpreted as representing an objective rather than qualifying a state. Such perspective allows identifying the trend by evaluating if a socio-economic system is getting closer to or moving away from an ideal.

The World Conservation Union sees three main conditions for society to claim sustainability (IUCN, UNEP & WWF 1991). Firstly, it must preserve the essential ecological processes that maintain life and biodiversity. Secondly, it has to guarantee the sustainable use of renewable resources and minimise the use of non-renewable ones. Thirdly, its activities are required to remain within the carrying ecological capacity.

The slight weakness of this argumentation that might be pointed out, from the operationalisation point of view, is that the concept of carrying capacity remains difficult to reliably quantify, as recently exemplified by Rockstrom et al. (2009), because of its dynamic characteristic (Meadows et al. 1992) on one hand, and on the other because it strongly depends on assumptions in regards to social metabolism (Martinez-Alier 1999). The ecosystems are complex, with innumerable interactions between them. This interdependency, amongst other factors, together with our limited knowledge thereof does not allow for a clear estimation of the anthropogenic burden ecosystems could safely handle.

[3] For more information, see www.globalenergyassessment.org.

Research on the Earth ecosystems' history provides numerous examples of changes, progressive or sudden, that occurred naturally. Sea level variation, global average temperature change, biodiversity modifications are all illustrations that natural systems are dynamic and self-evolving. Therefore, sustainability is anything but a static concept, as long-term equilibria, whether with or without anthropogenic interaction, have never existed.

There are several attempts to pinpoint a definition of sustainable development. Officiating as landmark and widely used as reference, the World Commission on Environment and Development (WCED)[4] coined one definition as follows:

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.* (WCED 1987)

The report further describes two key concepts. 1) The concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and 2) the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

This definition received a wide acceptance within the international community, although it was also relatively often criticised for its vagueness (Lélé 1991; Kates, Parris & Leiserowitz 2005). For example, what are the so-called needs referred to in the 'Brundtland's definition'? While some basic life requirements, like food and shelter, clearly fall under that category, others are disputable and socially constructed.

Beside the debate on whether something is a need or a luxury, there is as well the more subtle debate between the universal and objective needs and the culturally shaped ones (Preston 1996). The former represents a set of minimum physiological requirements whilst the latter implies a material and cultural minima. A list of needs is unlikely to be identical in different cultural contexts. As well, it would be mistaken to take for granted the fact that the needs of future generations will be equivalent to the ones of the present generation. Moreover, future generations have no agents and therefore no means of defending their preferences (Martinez-Alier 1987; Padilla 2002). Therefore, advocating future needs represents a challenge for current populations.

Luke (2005) questions the rhetoric of sustainable development, describing it as ideologically constructed in contemporary global society, and arguing that other strong interests, mainly economic, prevail in our 'unsustainably non-developmental material culture' (Luke 2005, p. 236). There is a clash in the interpretation of the notion of sustainable development between two fundamental positions. Both environmental economists and ecological economists advocate the preservation of natural capital. However, for the operationalisation, the former apply an economic value to that stock while the latter refer to it different units physical aspects (Özkaynak, Devine & Rigby 2004).

In spite of the divergent interpretation and critiques, in my view the concept of sustainable development is neither abstract nor elusive. There is a convergence on three key goals. Firstly, 'human beings should be able to enjoy a decent life'; secondly, 'humanity should become capable of respecting the finiteness of the biosphere'; and thirdly, 'neither the aspiration for the good life nor the recognition of the global biophysical limits should preclude the search for greater justice in the world' (Sneddon, Howarth & Norgaard 2006). The novelty in the concept lies in the fact that economic and social development is postulated as being compatible with the preservation of essential ecological conditions of human existence (Haberl et al. 2011).

As well, there seems to be a consensus in the literature for seeing sustainable development as multidimensional dynamic process (Newman 2005; Martens 2006; Giampietro, Mayumi & Munda 2006), including at least social, environmental and economic aspects (Martens 2006). Perhaps more importantly, the concept of sustainable development represents a cornerstone in that it epitomises a

[4] Commonly referred to as the Brundtland report, which is named after the Chair of the Commission Gro Harlem Brundtland.

significant shift of thinking whereby development is not considered as being in contradiction to environmental conservation. One has also to recognise the persuasive power and thus political strength and potential for broad social acceptance (Lélé 1991) of a concept that is all-encompassing, yet relatively straightforward to grasp and flexible in its interpretation.

1.2.2. Anthropogenic interference with the climate system

Climate change, alongside with biodiversity loss, is often described as being one of the major contemporary environmental challenge humankind is facing nowadays (Ramos-Martín 2001; Watkiss et al. 2005). Obviously the Earth is in a state of constant change and evolution, and the Earth's climate has always varied naturally. However, according to the vast quantity of international literature commenting on these matters, at least since Svante Arrhenius in late 19th century[5] if not before, the majority of scientists are now confident that the current trend is distinct, especially in terms of the rate at which the change is happening.

There has been a clear increasing trend in the concentration of carbon dioxide in the atmosphere during the industrial area, going from a concentration in pre-industrial area of below 300 parts per million (ppm) to nearly 400 ppm nowadays[6]. Observations and measurements show a global average temperature increase, snow and ice covers decrease, global average sea level rise, change in precipitation patterns, as well as an increase of the intensity and frequency of extreme weather events (Houghton et al. 2001). All these changes are measured as occurring over a relatively short period of time.

The difficulties and uncertainties of modelling an extremely complex system, such as the Earth's climate, lead to a wide range of estimates and strongly depend on different hypotheses and algorithms used. Nevertheless, the Intergovernmental Panel on Climate Change (see Parry et al. 2007) predicts an increase of the mean surface temperature of 1.1 to 6.4°C by the end of the 21st century, with an important driver of such rapid global climate change being the raising concentration of Greenhouse Gases (GHG) in the atmosphere. There is new and strong evidence that most of the recent warming observed is attributable to human activities (Solomon et al. 2007).

Preoccupations for anthropogenic climate change did not emerge on the political agenda until the mid-1980s. Indeed, the scientific evidence of human interference with the climate system started to raise public concern only shortly before the United Nations (UN) Earth Summit of 1992 (UNFCCC 2005). The consequences of a global average temperature rise of a few degrees are numerous, diverse and alarming, particularly on the most vulnerable. The projected changes in the climate patterns could alter ecosystems which are fundamental to humankind and other species as well as, amongst other effects, disrupt agricultural production, water cycles and resources.

1.2.3. Access to modern energy services and energy inequality

Still nowadays, a sizable share of the world's population lacks access to modern energy. An estimated 1.3 billion people do not have access to electricity, and 2.7 billion people rely largely on traditional biomass for cooking (IEA 2011). Energy represents an essential ingredient of socio-economic development.

Within underprivileged communities, an important part of the time and physical energy are spent on basic subsistence activities. This may promote a marginalisation of such populations and limit their ability to improve their living conditions.

The consequences of those precarious conditions can lead to poor education, inadequate healthcare and hardship on women and children. Children are sometimes withdrawn from school to collect and transport firewood, fetch water or even work in order to contribute to the very limited family budget.

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5 See Arrhenius (1896).

6 Measured at 390 ppm in December 2010 at Mauna Loa Observatory; data source: http://www.esrl.noaa.gov/gmd/obop/mlo/.

With direct and dire impacts, the use of traditional fuels for cooking and heating can have serious adverse effects on people's health (Holdren et al. 2000; Rehfuess, Mehta & Prüss-Üstün 2006; Smith 2010; Parikh 2011). Indoor pollution, caused by cooking fires, is affecting mainly women and children. The lack of fuel alternatives for cooking purposes can also lead to disastrous environmental impacts in the case of scarcity of supply. Yet, household energy for cooking tends to get less public policy attention than electrification, although both areas are fundamental to achieving universal access to modern, clean energy services (Bazilian, Cordes, et al. 2011).

The inequality in the access to energy services is manifest. Such issue is well illustrated by night-time light satellite imagery[7]. It provides a spatial sense of the issue of energy poverty. Figure 1-1 shows that, for instance, African continent remains largely in the dark, with the exceptions of a few areas, notably in North Africa, along the Nile, and in South Africa.

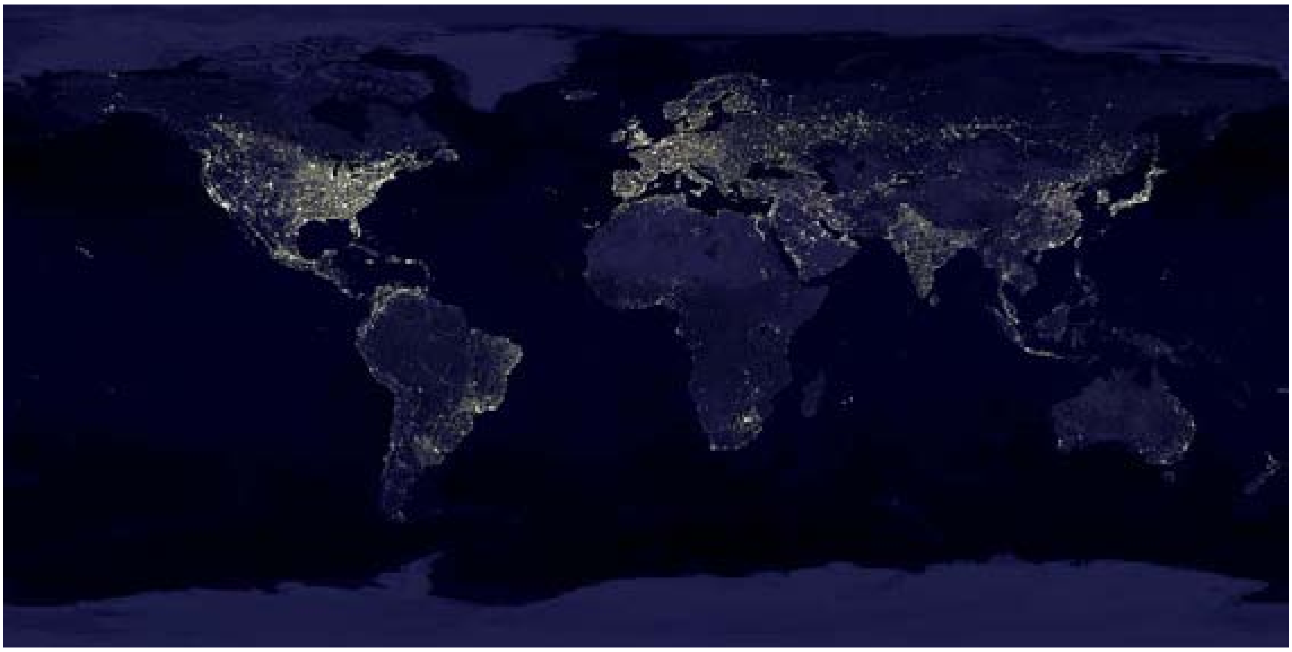

Figure 1-1: Night-time light satellite image of the earth

Source: National Aeronautics and Space Administration (NASA), http://visibleearth.nasa.gov

More rigorously, Figure 1-2 shows that the disparity in terms of (non-food) energy consumption throughout the world population is nearly as prominent as that of wealth. This graphical representation in a Lorenz curve underlines that 11% of the world's population consumes over half of the total energy. On the other side of the affluence spectrum, half of the world's total population uses as little as 10% of the total energy.

[7] It is recognised the night light imagery represents an imperfect proxy for energy poverty as it only captures electricity consumption through lighting, which represents a marginal fraction of total energy use. Also, differences in population density are not controlled for.

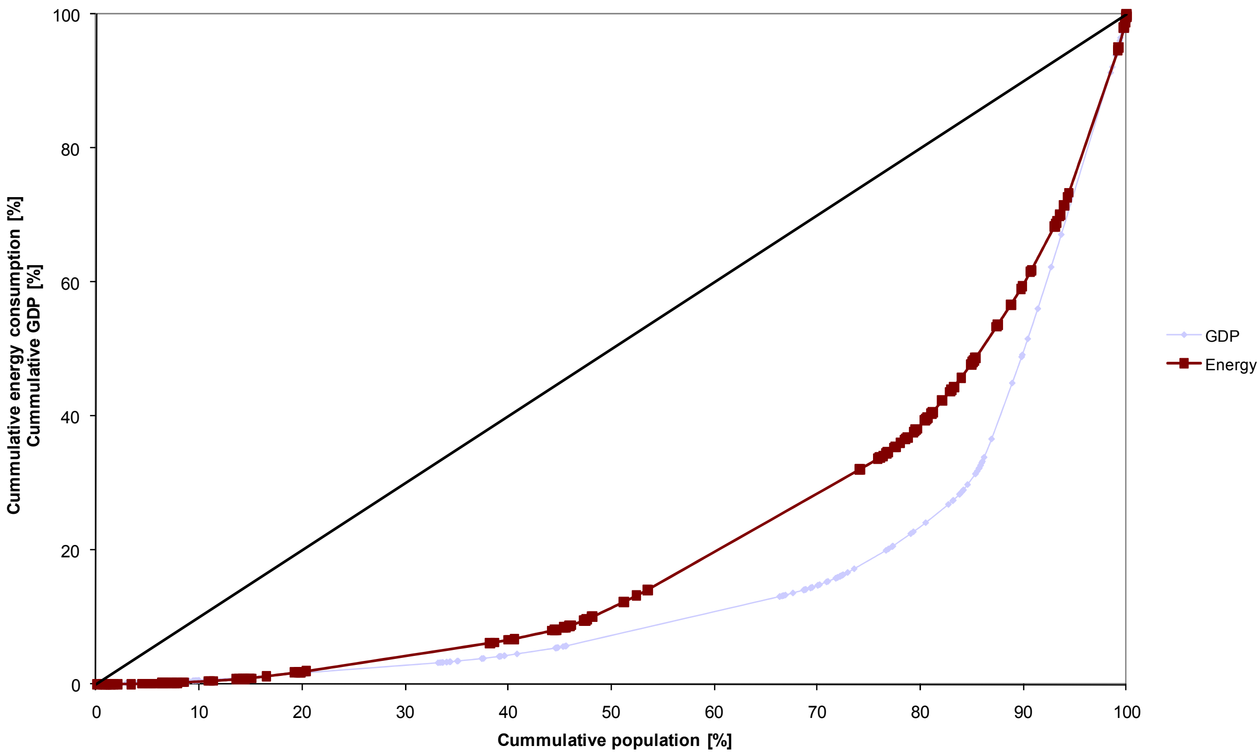

Figure 1-2: Lorenz curve of primary energy consumption and GDP at global level

Source: own compilation of data from U.S. Energy Information Administration and UNSD, aggregated at national level for 2008

Moreover, the proportion of the household income spent by poor families for indispensable energy services is greater than in wealthy families. This difference is evident both from a local as well as global perspective. Absolute energy spending usually rises with income, but generally at a less than proportional rate (IEA 2002). Furthermore, the poorest frequently relinquish or compromise even on basic services like lighting and space heating. As shown in the Figure 1-3, the proportion of income spent on energy services tends to be higher for the poorest than the richest portion of the population in a given country. This proportion can be very high for the poor in so-called least developed countries (LDC).

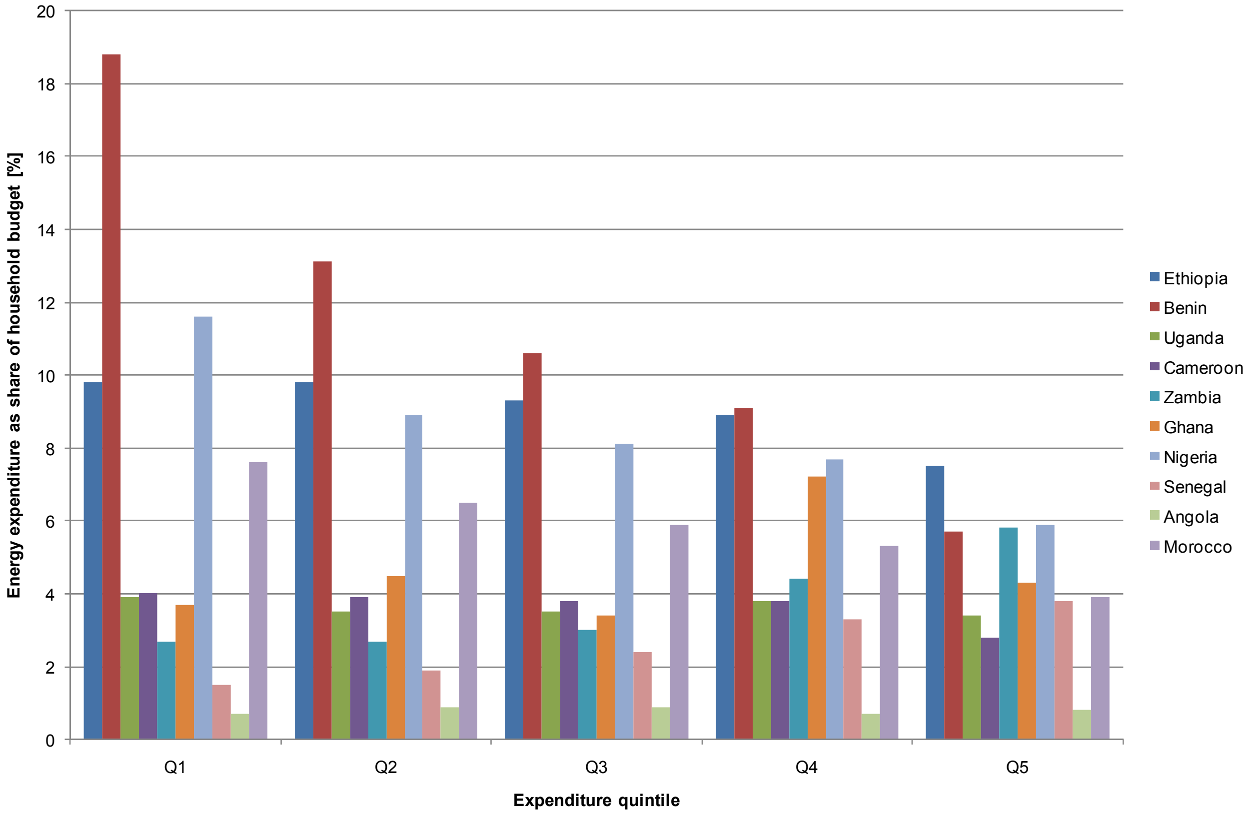

Figure 1-3: Share of energy expenditure by income classes for selected African countries

Note: Q1: poorest; Q5: richest. Data source: Banerjee et al. (2008)

In a similar vein, and at first sight incongruously, the poor typically pay a relatively high price for an energy service of low quality (Johansson & Goldemberg 2002). Figure 1-4 shows the amortized daily costs for a single family to access the suite of basic lighting, cooling, and communication services. The cost of these services is calculated against a baseline in which kerosene lighting and a lead-acid battery is used. The daily cost of the energy services is plotted against the amount of energy that is needed to support these services over the course of a year.

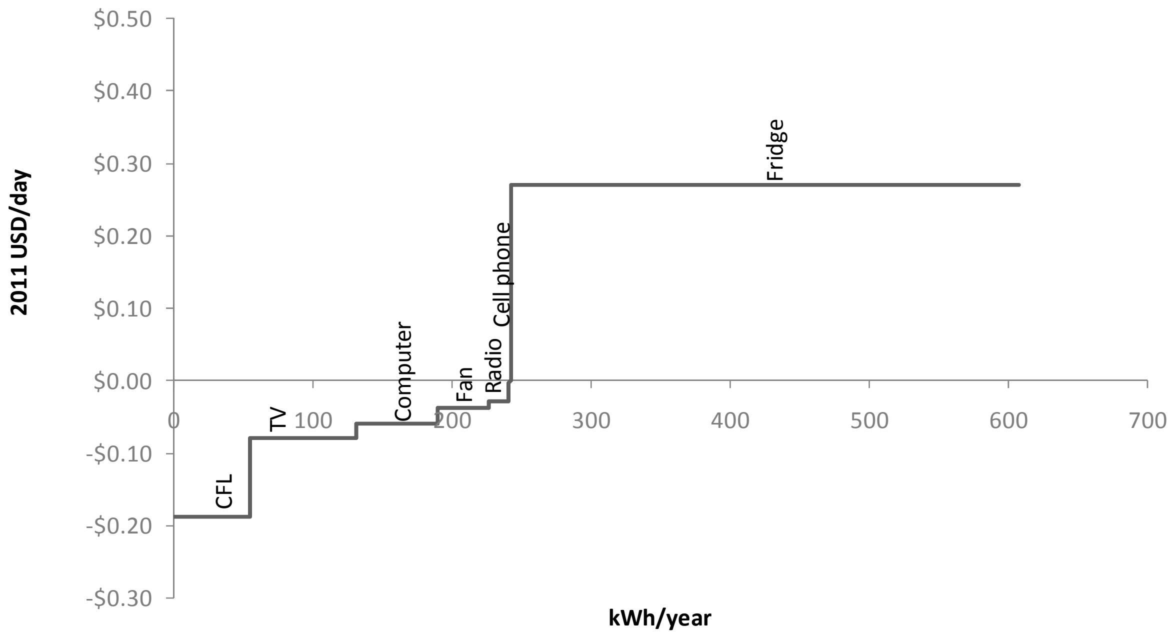

Figure 1-4: Cost curves for basic household modern energy services based on grid

Note: CFL: Compact Fluorescent Lamp. Source: Casillas, Nussbaumer, Kammen & Bazilian (in preparation). Universal access to modern energy services by 2030

The daily costs provide insight into the financial burden (or relief) on a household using such an energy service, while the annual energy consumption correlates to the amount of available capacity that is needed to access the energy service. The annualized daily cost includes capital cost plus energy cost.

The baseline (lack of access to modern energy services) used to compute the cost curve is normative in nature and obviously varies depending on the context. It nevertheless illustrates the fact that poor households commonly overspend for energy services that are often inferior. Indeed, using a hurricane kerosene lamp for lighting is more costly than efficient light bulbs powered by electricity, and provides significantly poorer illumination (Mills 2005). Accessing modern energy services not only significantly improves the living standard, but also has the potential to lessen the burden on the already stretched budget of poor households.

It is important to note the difference between various energy services. Efficient lighting unambiguously makes economic sense, both in the case where the electricity is provided by the grid or by means of a microgrid, which tends to be more expensive. Refrigeration costs significantly more than the other services. With proper financing, adequate lighting would amount to a small fraction of poor household's expenditures, while refrigeration would be significantly larger.

It must be underlined here that these cost curves are not to be interpreted as a form of 'energy ladder'[8], in which individuals consume the more expensive energy services in succession, as they are able to afford them. People have different 'willingness to pay' for different quantities and types of energy services.

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[8] The concept of 'energy ladder' refers to a shift of the dominant household fuel used as a function of income (see e.g. Reddy 2000). Whilst useful a model at conceptual level, it is arguably simplistic and misleading as empirical evidence demonstrates that the process is not gradual and that many other factors come to play (e.g. cultural choices, technology availability).

The energy service cost curves are useful from a policy perspective. Promoting energy services that bear a 'negative' cost compared to the status quo will require a focus on addressing the issue of capital cost, as well as disseminating information regarding benefits of energy and cost savings (Jaffe & Stavins 1994). On the other hand, those services causing an additional cost (compared to the baseline) might require other forms of incentives, such as subsidies.

1.2.4. Energy transition

Current systems are inadequate to deal with major contemporary global challenges, such as climate change, poverty alleviation, etc. Key contemporary global challenges are contingent on energy systems. Moving towards sustainable development will require an energy transition that ought to incorporate issues related to equity and justice (Newell, Phillips & Mulvaney 2011).

Nothing short of a paradigm shift is required to adequately and timely address those issues. Concretely, we need to profoundly revisit the way we produce, transport and consume energy. The stakes are high, and poor developing countries are already paying the price (Patt et al. 2010) of problems they barely contribute to. This has given the rise to a stance taken by the a number of civil society organizations gathering under the banner of *Climate Justice*, claiming for payment of an 'ecological debt' or 'climate debt' (Roberts & Parks 2007).

A transition to inclusive, low-carbon economies is a pressing imperative. Meanwhile, carbon dioxide concentration in the atmosphere is increasing 2 ppm per year. Also, the recent revival of nuclear energy has received a big knock due to the review of energy strategies and national policies following the accident at the Fukushima-Daiichi plant in 2011. Moreover, there are many local conflicts (from France to Nigeria to Ecuador and Colombia to the United States) on the extraction and transport of the fossil fuels, whether shale gas, oil or coal. It was also from civil society that the strongest complaints have been heard against 'modern' biomass energy. Major criticisms have been levelled against biofuels in terms of their relatively low EROI (Energy Return On Energy Input) and also in terms of their impact on biodiversity (by increasing the HANPP, human appropriation of biomass, to the expense of other species, as in deforestation in Indonesia due to palm oil plantations) (Giampietro & Mayumi 2009).

The implied energy transition needed will be all-encompassing and require various combinations of policy measures, investment incentives, research and development, as well as lifestyle and value changes. In other words, a daunting task; a transformation to radically different, and inclusive, energy systems represents a generational challenge.

Energy being so central to every aspects of modern life implies that, a transformation can be lengthy, particularly if behavioural changes are required. But also, because of the relatively long legacy characterising energy systems, shifts are gradual rather than sudden. Therefore, decisions made today on energy systems leave a long legacy; it is therefore crucial to consider medium- to long-term elements, alongside the short-terms imperatives, when it comes to strategic decision on energy issues.

Fossil energy has fuelled our economies and allowed tremendous progress; yet, those resources are finite. Technologies systems based on those energies are therefore set to decline. Our industrial civilization is therefore at a crossroads, pushing Rifkin (2011) and others to call for a Third Industrial Revolution.

1.3. Creating a conducive environment

Left to market forces alone, energy systems are unlikely to evolve in such a way as to adequately address the range of issues described above. With this in mind, an enabling environment is required to foster the energy transition required.

Crucial ingredients include an appropriate institutional framework as well as a range of incentives. Policies represent a widely used instrument to steer investments towards predefined goals. The analyses presented in this Thesis have in common the objective of informing the design and implementation of such policies through evidence-based research.

1.3.1. Incentives and policy

There appears to be an emerging consensus on the diversity and difficult nature of the key energy issues, and the requirement to look at them in a holistic manner. This consensus should be considered an opportunity for leadership. The complexity of energy policy does not allow for simple solutions, governance, cooperation, or regulation. Energy policy attempts to simultaneously optimize a number of objective functions under numerous constraints that are non-linear, and uncertain. Some of the functions to be addressed include notably climate change (and environmental conservation more widely), energy security, energy prices and costs (both as a concern of business and residential consumers), and widespread access energy to modern energy services.

Energy policy is primarily conducted at national and regional levels, and very rarely in international fora. The recent recognition of the interconnectedness of many aspects related to energy policy, from social and economic development to climate change to security issues, creates a useful foundation for such a discussion to re-emerge. Energy is at the heart of social and economic development. It helps underpin democracy and equity. Access to clean energy and related services create the foundations for meeting the Millennium Development Goals.

1.3.2. Institutional framework and governance

A brief look at international energy governance[9] illustrates the intricacy. Overall, no institution has a remit across all sectors, technologies and regions. Various international organizations are involved in the energy sector. Yet, the energy source has traditionally set the bounds of the organizations (e.g. International Atomic Energy Agency, Organization of Petroleum Exporting Countries, International Renewable Energy Agency). They also often have specific constituency (e.g. OECD countries for the International Energy Agency), or focus on particular aspects (e.g. United Nations Industrial Development Organization, Food and Agriculture Organization). This institutional landscape has been complemented by a range of other bodies (e.g. Major Economies Forum on Energy and Climate) with various mandates.

Under the premise that an overarching energy organization, with comprehensive membership and mandate covering all major energy issues, is unlikely to be created (and possibly not desirable) in the foreseeable future, an alternative architecture is required to effectively address the most pressing energy challenges in a coordinated and concerted fashion. It is important to understand the strengths and weaknesses of the existing regime to identify the gaps and opportunities for improvements. The field of climate change, for which governance has received more scholarly attention, provides useful insights in that regard.

For several decades, world leaders have struggled with limited success to craft an all-encompassing regulatory system to deal with the issue of climate change. There is the view that distributional obstacles to policy together with the march of social metabolism (economic growth entails more energy and material use) explain the failures of international governance of climate change (Martinez-Alier 1993). Huq (2011) claims that the failure of global institutions in dealing effectively with climate change is primarily due to the fact that the prevailing paradigm, a bold move towards a low-carbon economy, is seen as a burden rather that an opportunity. From a structural viewpoint, Bodansky and Diringer (2010) argue that the sole focus on the multilateral approach might have precluded progress in addressing climate change, producing in some cases a state of perennial stalemate.

Following the frustration to reach agreement via the multilateral path, a number of countries have turned their attention to smaller, less formal frameworks (Levi 2010). Smaller groups of similarly-minded stakeholders can act as conduit to developing effective action frameworks. Lessons learnt from the last couple of decades of laborious climate negotiations indicate that the way forward ought to

[9] As governance, the suite of processes through which rules needed to achieve a given outcome are set and enforced is considered. It includes, but is not limited to, the role of governments. A myriad of other groups, ranging from small communities to much broader constituencies, also play a role.

encompass a more evolutionary approach to the development of the climate change regime (Bodansky 2011). Drawing from international economic law, which is characterized by "too many institutions and too little governance", Victor and Yueh (2010) note the series of ad hoc arrangements made that evolved into an effective management system. This notwithstanding, empirical evidence from the ADAM[10] project indicates that high degrees of fragmentation in global climate governance tends to reduce the overall performance, be more costly, less effective in terms of environmental goals, and also less equitable (Biermann, Pattberg & Zelli 2010).

In the context of the discussion around the desirable institutional architectures to promote a move towards a green economy[11], Selin and Najam (2011) call for bold thinking to address the enormity of the challenge, but incremental move in terms of institutional reform so as not to paralyze action due to the fact that big change can be difficult to process. They also highlight the need to better accommodate non-state actors, whilst acknowledging the fact that the role of the state is and will remain central.

Institutional reforms likely require going beyond revamping existing institutions. Dealing with today's challenges, changes in geopolitics, and increasingly vocal and powerful civil and economic society are powerful drivers for change. Future global governance mechanisms will likely be diverse and variegated in nature (WEF 2010). As eloquently described by Keohane and Victor (2010), the path forward on international governance could be a loosely coupled set of specific regimes: a regime complex.

In the absence of global governance architecture (and prospect for it), there are a number of means through which elements of global governance can be achieved. A traditional approach is through treaties: an agreement between two or more countries. Another way is via the creation of inter-governmental institutions. The strategies that facilitate or dictate the way states cooperate are referred to as 'regime'.

The concept of regime complex has enriched regime theory (Florini & Sovacool 2011). Early discussions around regime complex arose in the context of plant genetic resources (see Raustiala & Victor 2004). The core paradigm whereby governance is mainly ensured and enforced through interstate relations has been giving way to a model where a broad array of mechanisms is at play, representing a "collective of partially overlapping and non-hierarchical regimes" (Raustiala & Victor 2004). Alter and Meunier (2009), drawing from complex system theory, argue that the international governance realm with states, sub-states, supranational and transnational actors as building blocks and a myriad of agreements connecting these stakeholders can be considered as a complex system. That is, a network of heterogeneous components interacting without external organizing principles.

Some might argue that a regime complex represents a second-best option, if efforts to design a legitimate and, comprehensive regime fail. But the stalemate and the limited progress achieved in recent global climate negotiations make it likely that other routes are to be explored. Recently, many analysts highlight the advantages of the idea of regime complex, notably in terms of flexibility, adaptability, political feasibility. This paradigm shift creates an opportunity to reform global energy governance towards an effective framework to address critical global and cross-cutting energy issues in the absence of an integrated, comprehensive regime. Commonly, a regime complex is not designed, but rather emerges as a result of strategic decisions made by various stakeholders at various times.

1.4. International cooperation

Symptomatic to the uniqueness and complexity of the challenge faced nowadays is the conjunction of new key global issues to be dealt with simultaneously. Climate change mitigation and adaptation cannot make abstraction of the major economic crisis that a large part of the world is still battling with at the time of writing. The financial downturn drastically reduced the availability of much needed capital to invest in aging energy systems already challenged by increased energy demand and population growth.

[10] ADAM Project: Adaptation and Mitigation Strategies: Supporting European Climate Policy; www.adamproject.eu.

[11] UNEP defines a green economy as one that results in "improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP 2010).

Also, the recent succession of crises (food, energy, economic) took a harsh toll on the world's poor, and may wipe out some of the recent direly acquired developmental progress. Notwithstanding the fact that policies are typically designed and enforced at national level, those tremendous issues go well beyond both national remit and capacity.

On a different, but related issue, the geopolitics of energy should not be underestimated. Such considerations are at the core of the linkages between energy, security, climate change and poverty. Energy security is not merely of concern to industrialised countries. The economic implications of unreliable energy services are daunting. A number of developing countries suffer from inadequate generation capacity, limited electrification, inefficient systems and high production and distribution costs. Chronic energy problems take a heavy toll in terms of losses in economic growth and productivity. Estimates of the cost of power shortages reveal that they may exceed several per cent of GDP (Foster & Briceno-Garmendia 2010).

Trade is another sensitive dimension of energy that requires serious attention (Yumkella 2011). Trade in energy carriers, technology transfer, intellectual property rights and institutional framework all have widespread implications. They must be addressed in a comprehensive fashion. The controversy on the Keystone XL pipeline that would carry oil from the oil sands in Alberta, Canada to the southern and eastern United States is a current example. Developing countries must not follow the dirty development path taken many decades ago by the now industrialised countries.

1.4.1. Learning from the past

This rapidly evolving landscape has challenged the development community, and has required swift adjustments in the orientation of development policies. Indeed, the thinking in the development community has evolved remarkably over recent decades. In the mid-20th century, the focus on the accumulation of physical capital as the primary means to catch up with industrialised countries gradually gave way to the recognition of the importance to invest in human capital. This trend was followed by ideas derived from the Washington Consensus which pointed towards accelerating structural changes, liberalization, deregulation and privatization. However, the overwhelming emphasis on macroeconomic orthodoxy did not always deliver its promise to promote sustainable and equitable development. This realization led to a series of reforms addressing institutional shortcomings.

The lesson that can be drawn from the past is that development strategies should encompass, *inter alia*, well designed, context-specific policies, macroeconomic stability and a flexible institutional framework. The contemporary development agenda has become broader and more complex. There is a common understanding in the development community that a number of major challenges are intrinsically interrelated.

The concept of first and third world, with its implicit reference to donor and recipient in the context of development cooperation, belongs to history and is inappropriate now. We live in a multi-polar, rapidly evolving world. Multilateralism must therefore evolve to better serve the mutual interests and responsibilities of both industrialised and developing countries, while recognising different perspectives and circumstances. Modern multilateralism is about engaging with new players, harnessing global and regional institutions to help address threats and seizing opportunities that surpass the capacities of individual states (Zoellick 2010).

This evolving context has tremendous consequences on the way the international community addresses energy-related challenges. In that regard, and in line with the proposal of the former IAEA Director General, Mohamed ElBaradei to create a global energy organization (ElBaradei 2008), energy issues would benefit from being addressed in a coordinated and holistic fashion at the institutional level.

1.4.2. International organisations

The UN system has worked on energy issues for decades, but in a rather fragmented manner. Responding to the need for a concerted UN strategy on energy issues, UN-Energy was established. This inter-agency mechanism for coherence and cooperation on energy issues aims at effectively combining the experience of some 20 United Nations agencies to implement sustainable energy solutions.

Since its inception in 2004, UN-Energy has been instrumental in sharing information and good-practices on energy within the UN system. It has also served as a platform for partnerships among various UN organizations and for coordinating their energy-related programmes and activities. Since there is no single United Nations entity that has primary responsibility for energy, UN-Energy is vital for a focused and collective UN engagement across the energy field.

In addition to this, Ban Ki-moon, the current Secretary-General of the United Nations, decided to set up a consultative body in June 2009, the Advisory Group on Energy and Climate Change (AGECC). While the UN system is well placed to play a major role, its achievements can be greatly increased by joining hands with other actors. The AGECC aimed at uniting cutting-edge expertise and experience related to sustainable energy. Its members included the heads of some of the world's most successful energy companies. The visionary thinking of these world leaders can help to chart a clear course for the UN with regard to energy and climate change issues.

The AGECC is a prime example of a multi-stakeholder partnership bringing together the UN system, including the World Bank, with the private sector and research institutions. Its work has benefited from a unique mix of policy orientation, technical expertise and business experience of leading figures in the field of energy. After a number of meetings, the AGECC produced a report that was presented to the Secretary-General. The report calls on the United Nations and its Member States to commit themselves to two complementary goals (AGECC 2010), namely, to ensure universal access to modern energy services by 2030; and to reduce global energy intensity by 40% by 2030.

The report makes a couple of points clear. First, it is unacceptable that a third of humanity has no access to modern energy services and that half of humanity has to rely on traditional biomass for meeting their basic energy needs. Eliminating energy poverty is of paramount importance to eradicating poverty. It is also essential to the achievement of the other Millennium Development Goals. Second, the vast potential for energy efficiency improvements across the energy supply and delivery chain remains largely untapped.

Subsequently, the UN Secretary-General launched a new initiative: Sustainable Energy for All (SE4ALL). Building up on AGECC, SE4ALL is articulated around three aspirational goals for 2030. Those are (United Nations 2011):

- Ensuring universal access to modern energy services;
- Doubling the rate of improvement in energy efficiency;
- Doubling the share of renewable energy in the global energy mix.

Related to this, 2012 has been declared by the General Assembly, the main deliberative, policymaking and representative organ of the United Nations, as the *International Year of Sustainable Energy for All*.

During the past few years, energy has dramatically moved up the agenda at national and global level. It should always have been there, due to its centrality. The prominence of energy is reflected in debates on its role in global security, environment and development. The clear understanding that energy is an essential part of addressing all of these issues is further underlined by the four-fold increase in annual global clean energy investments—from USD 36 billion in 2004 to 145 billion in 2009 (WEF 2009).

Concerted global efforts are required to develop and implement smart policies. Fortunately, a broad range of options that can effectively address energy-related challenges exists today. As an example, modern systems based on renewable energy can be an effective tool for helping the 2–3 billion people worldwide who still lack access to energy services. Likewise, energy efficiency measures are now well understood and can serve as a foundation for national energy plans, with a careful consideration of the rebound effects[12]. International cooperation can help catalyze the required actions.

1.5. Structure and composition of this Thesis

This section provides an overview of the structure and composition of this Thesis, and offers a brief narrative describing each chapter.

The various chapters form a coherent ensemble of individual pieces of analysis around the backbone of this Thesis, namely the nexus between energy, poverty and socio-economic development. The different chapters, which represent stand-alone articles, provide contrasting and complementary perspectives around the issue at hand. They consist of applied research as well as methodological development. This Introduction, and the Conclusion to the Thesis, bind the threads together.

Whilst I have produced some elements as sole author, the articles have benefited by input from, and collaboration with, various co-authors. I have substantially contributed to all articles featured in this Thesis – the specifics of my contribution to each article are given below. I assert here that, to the best of my knowledge, none of those articles are being or have been submitted as part of another doctoral Thesis. In addition to the substantive chapters of this Thesis, sections from the Introduction and Conclusion also draw from my contribution to a number of other publications[13].

The Thesis, an overall assessment of energy for sustainable development, is organised in such a way so as to present a consistent and structured narrative. In broad structural terms, the Thesis starts by gauging the issue of energy poverty, or the lack of access to modern energy services, in the first chapters. Those offer a sense of the magnitude of the challenge at hand, as well as present as assessment on scenarios towards universal energy access. In the following chapters come insights on the scale of investment required to address the issue. Finally, concrete interventions to overcome some of the issues are discussed.

In detail, Chapter 2 presents an assessment of the link between energy and the Millennium Development Goals (MDG). While intuitive, such relationship is difficult to quantitatively ascertain and

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[12] The rebound effect refers to the behavioral or systemic responses to the introduction of new technologies that increase the efficiency of resource use. These responses tend to offset the beneficial effects of the new technology or other measures taken. The rebound effect, also referred to as 'Jevons paradox', was first described by William Stanley Jevons in the context of efficiency improvement of coal-fired steam engines (see Jevons 1865).

[13] Including:

Casillas, Ch, Nussbaumer, P, Kammen, D & Bazilian, M (in preparation), "Universal access to modern energy services by 2030";

Bazilian, M, Nussbaumer, P, Nakhooda, S, Burrell, L, Aqrawi, P. (in preparation), "Global Energy Governance for the Poor";

Bazilian, M, Nussbaumer, P, Eibs Singer, C, Brew-Hammond, A, Modi, V, Sovacool, BK, Ramana, V, Aqrawi, P.-K, n.d., "Improving Access to Modern Energy Services: Insights from Case Studies," *The Electricity Journal*, vol. In Press, Corrected Proof;

Yumkella, K, 2011, Multilateralism and Energy for Development. In FL Toth, ed. *Energy for Development: Resources, Technologies, Environment*. Dordrecht, Netherlands: Springer;

Bazilian, M, Cordes, L, Nussbaumer, P & Yager, A 2011, "Partnerships for access to modern cooking fuels and technologies," *Current Opinion in Environmental Sustainability*, vol. 3, no. 4, pp. 254-259;

Bazilian, M, Nussbaumer, P, Cabraal, A, Centurelli, R, et al. 2010, *Measuring Energy Access - Supporting a Global Target*, The Earth Institute, Columbia University;

Patt, A, Tadross, M, Nussbaumer, P., Asante, K, et al. 2010, "Estimating least-developed countries' vulnerability to climate-related extreme events over the next 50 years." *Proceedings of the National Academy of Sciences*, pp. 1-5;

Nussbaumer, P 2007, "Working of Carbon Market," *Economic and Political Weekly*, vol. XLII, no. 30, pp. 3081-3085; and

Nussbaumer, P 2006, "Clean Development Mechanism and Sustainable Development," Master Thesis, Universitat Autònoma de Barcelona.

thus has not been analytically explored in detail in the scientific literature. The correlation between access to energy services and development is, however, often addressed in aggregate in the literature, for example by using composite indexes such as the Human Development Index (HDI), or by focusing strictly on economic impacts. This analysis presents a statistical articulation of the link between energy and various proxies of development, using the Millennium Development Goals as a framework. The outcomes confirm the potentially positive influence of access to energy services on development. The assessment provides a perspective on a number of often employed assumptions about the correlation between energy and development, and challenges claims of its universally positive benefits to specific development priorities. This research finds that the benefits to development of access to energy services vary considerably. It derives from a paper that has been submitted[14] for publication in *Climate and Development*. The analysis has been undertaken in collaboration with co-authors who provided conceptual support. I conceptualised and developed the idea based on a literature review, developed, tested and applied the methodology, carried out the analysis and drafted the paper.

Chapter 3 deals with the issue of quantifying energy poverty. Effective policies to dramatically expand modern energy access need to be grounded in a robust information-base. Metrics that can be used for comparative purposes and to track progress towards targets therefore represent an essential support tool. This analysis reviews the relevant literature, and discusses the adequacy and applicability of existing instruments to measure energy poverty. Drawing on those insights, I propose a new composite index to measure energy poverty. Both the associated methodology and initial results for several African countries are discussed. Whereas most existing indicators and composite indices focus on assessing the access to energy, or the degree of development related to energy, our new index – the Multidimensional Energy Poverty Index (MEPI) – focuses on the deprivation of access to modern energy services. It captures both the incidence and intensity of energy poverty, and provides a new tool to support policy-making. This research forms the basis of a paper that has been issued[15] as a working paper by the University of Oxford, and then published[16] in *Renewable & Sustainable Energy Reviews*. It has been undertaken in collaboration with co-authors who contributed to the overall analysis by providing conceptual support. I conceptualised and developed the idea based on a literature review, developed, tested and applied the methodology, carried out the analysis and drafted the paper.

Chapter 4 depicts power sector scenarios for Africa. In order to reach a goal of universal access to modern energy services by 2030, consideration of various electricity sector pathways is required to help inform policy-makers and investors, and help guide power system design. To that end, and building on existing tools and analysis, several 'high-level', transparent, and economy-wide scenarios for the sub-Saharan African power sector to 2030 are presented. These simple scenarios are constructed against the backdrop of historical trends and various interpretations of universal access. They are designed to provide the international community with an indication of the overall scale of the effort required. Most existing projections, using typical long-term forecasting methods for power planning, show roughly a threefold increase in installed generation capacity occurring by 2030, but more than a tenfold increase would likely be required to provide for full access – even at relatively modest levels of electricity consumption. This equates to approximately a 13% average annual growth rate, compared to a historical one (in the last two decades) of 1.7%. This research forms the basis of a paper issued[17] as a

[14] Nussbaumer, P, Bazilian, M & Patt, A (under review), "An empirical assessment of the relationship between energy and the Millennium Development Goals."

[15] Nussbaumer, P, Bazilian, M, Modi, V & Yumkella, K 2011, *Measuring Energy Poverty: Focusing on What Matters*, Oxford Poverty & Human Development Initiative, University of Oxford. Available at: http://www.ophi.org.uk/measuring-energy-poverty-focusing-on-what-matters/.

[16] Nussbaumer, P, Bazilian, M & Modi, V 2012, "Measuring energy poverty: Focusing on what matters," *Renewable and Sustainable Energy Reviews*, 16, pp. 231-243.

[17] Bazilian, M, Nussbaumer, P, Rogner, H.H, Brew-Hammond, A, Foster, V, Pachauri, S, Williams, E, Howells, M, Niyongabo, P & Musaba, L 2011, *Energy Access Scenarios to 2030 for the Power Sector in Sub-Saharan Africa*, Nota di Lavoro 2011.68, Fondazione Eni Enrico Mattei. Available at: http://www.feem.it/getpage.aspx?id=4244&sez=Publications&padre=73 .

working paper by the Fondazione Eni Enrico Mattei, and then published[18] in *Utilities Policy*. I conducted the literature review, analysed historical trends and technology portfolio assessment, contributed to developing the projections and analysis, and drafted the article.

Chapter 5 deals with the scale of investment required to reach universal energy access. To help provide clarity in this area, support political decision making, and inform the design of financial responses, the overall scale of spending required to meet universal access to modern energy services is considered. The existing literature at the global, regional, national, and project levels and disaggregate cost estimates is reviewed in order to provide increased transparency through comparable metrics. A new methodology is developed to calculate three new cost scenarios that attempt to address several existing analytical gaps. As a conclusion, the total cost of providing (near) universal access is expected to be considerably higher than published estimates which often focus primarily on capital costs. While recognizing the coarse nature of the analysis, the annual cost of universal access to electricity and clean cooking is estimated at ranging from USD 14 to 136 billion (USD 12 - 134 billion for electrification and USD 1.4 to 2.2 billion for clean cooking), depending on the assumptions about the level of energy access notably. This original research forms the basis of an article published[19] in *Geopolitics of Energy*. This analysis has been carried out in collaboration with colleagues from various institutions and disciplines. I conducted the literature review and gathered the data, scoping of the paper, developed and applied the methodology, performed the analysis, and drafted the article.

Chapter 6 presents a follow up analysis by assessing the current international financial flows for energy. To help inform the design of appropriate and effective policies to reduce energy poverty, this analysis presents an assessment of the current macro financial flows in the electricity and gas distribution sectors in developing countries. It builds on the methodology used to quantify the flows of investment in the climate change area. The approach relies on national gross fixed capital formation, overseas development assistance, and foreign direct investment. These high-level and aggregated investment figures provide a sense of the scale to policy-makers, but are only a small part of the information required to design financial vehicles. In addition, these figures tend to mask numerous variations between sectors and countries, as well as trends and other temporal fluctuations. Nonetheless, for the poorest countries, one can conclude that the current flows are considerably short (at least five times) of what will be required to provide a basic level of access to clean, modern energy services to the 'energy poor'. This original research forms the basis of an article issued[20] as a working paper by the Fondazione Eni Enrico Mattei, and then published[21] in *The Electricity Journal*. In the framework of this analysis, I conducted the literature review and participated in the data gathering, contributed to the development and application of the methodology, performed the analysis, and participated in the drafting of the article.

Chapter 7 presents applied research on a policy mechanism to address climate change and promote sustainable development. The Clean Development Mechanism (CDM) has a twofold objective, to offset greenhouse gas emissions and to contribute to sustainable development in the host country. The contribution to the latter objective seems marginal in most CDM activities. Also, CDM activities are unevenly spread among developing countries. In response to these concerns, initiatives with the objective of promoting CDM projects with broad local sustainable development dividends have been

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[18] Bazilian, M, Nussbaumer, P, Rogner, H-H, Brew-Hammond, A, Foster, V, Pachauri, S, Williams, E, Howells, M, Niyongabo, P, Musaba, L, Gallachóir, BÓ, Radka, M & Kammen, DM 2012, "Energy access scenarios to 2030 for the power sector in sub-Saharan Africa," *Utilities Policy*, vol. 20, no. 1, pp. 1-16.

[19] Bazilian, M, Nussbaumer, P, Haites, E, Levi, M, Howells, M, & Yumkella, K, 2010, "Understanding the Scale of Investment for Universal Energy Access" *Geopolitics of Energy*, vol. 32, no. 10-11, pp. 19-40.

[20] Bazilian, M, Nussbaumer, P, Gualberti, G, Haites, E, Levi, M, Siegel, J, Kammen, D & Fenhann, J, 2011, *Informing the Financing of Universal Energy Access: An Assessment of Current Financial Flows*, Nota di Lavoro 2011.56, Fondazione Eni Enrico Mattei. Available at: http://www.feem.it/getpage.aspx?id=4126&sez=Publications&padre=73.

[21] Bazilian, M, Nussbaumer, P, Gualberti, G, Haites, E, Levi, M, Siegel, J, Kammen, D, & Fenhann, J, 2011, "Informing the Financing of Universal Energy Access: An Assessment of Current Flows," *The Electricity Journal*, 24(7), pp. 57-82.

launched, such as the Gold Standard and the Community Development Carbon Fund. The Gold Standard label rewards best-practice CDM projects while the Community Development Carbon Fund focuses on promoting CDM activities in underprivileged communities. Using a multi-criteria method, the potential contribution to local sustainable development of those CDM projects with particular attributes is compared with ordinary ones. This evaluation suggests that labelled CDM activities tend to slightly outperform comparable projects, although not unequivocally. This original research forms the basis of an article published[22] in *Energy Policy* which itself stems from work originally carried out in the framework of my Masters Thesis and was further expanded and complemented for publication. While acknowledging sporadic input from colleagues, I carried out this analysis and am the sole author of the article.

Chapter 8 delineates areas of possible further work related to the research presented herein. And finally, Chapter 9 offers overall conclusions.

[22] Nussbaumer, P, 2009, "On the contribution of labelled Certified Emission Reductions to sustainable development: A multi-criteria evaluation of CDM projects." *Energy Policy*, vol. 37, no. 1, pp. 91-101.

2. Energy and the Millennium Development Goals: a statistical analysis of key indicators

2.1. Introduction

Two major challenges are confronting the energy system, namely the need to ensure the supply of affordable and reliable energy whilst at the same time drastically curbing related greenhouse gas (GHG) emissions. Those issues are intrinsically intertwined.

Fossil fuels dominate, and are expected to continue to do so in the foreseeable future, the energy landscape. Despite a significant increase in the deployment of low-carbon technologies in the recent years, heat supply, electricity generation and transport generate around 70% of global GHG emissions (Metz et al. 2007).

A sizable share of the world's population lacks access to modern energy. An estimated 1.5 billion people do not have access to electricity (IEA 2009b), and 2.5 to 3 billion people rely on traditional biomass for cooking (IEA 2009b; UNDP & WHO 2009). Energy is essential to many aspects of human development due to the wide array of services it delivers in the form of light, mechanical power, process heat, space heating, motive power for transport, water pumping, etc.

Energy is thus often assumed to be a prerequisite to all aspects of economic and social development. While intuitive, better insights with regard to the links between energy and different aspects of development is crucial for designing effective and well-focused policies and measures aimed at supporting human development. This paper addresses a gap in the literature by statistically analyzing the specific links between selected energy indicators and several proxies of development, utilising the Millennium Development Goals (MDGs) as a framework.

In section 2.2, we review the literature relevant to the energy-development nexus, both generally and in the context of the MDGs. Section 2.3 describes the methodology used to assess the link between energy and development. The results of the analysis are presented in section 2.4, which is followed by a discussion in section 2.5.

2.2. The Energy-Poverty-Development nexus

Energy does not directly represent a vital human requirement *per se*[23]. It is, however, crucial to the fulfilment of many basic human needs and services (Najam & Cleveland 2003). It is widely recognised that provision of energy services alone will not reduce poverty (DFID 2002); it is a necessary but insufficient condition to human emancipation. However, it is often argued that access to reliable, affordable energy services plays a critical role for development (UN-Energy 2005).

2.2.1. General findings

Modi (2004) suggests that, given climatic and other variations, there is a quantifiable minimum amount of energy necessary to avoid seriously compromising human survival. Such quantifications are available in the World Energy Assessment (Goldemberg et al. 2000, p. 369), for instance. Beside the energy required to sustain basic life, such as the ability to cook food or stay warm (Goldemberg & Johansson 1995), humans need additional energy to support education, health care, social enhancement, and access to safe water, as well as to provide means of being economically productive. In addition to the quantity requirements, qualitative aspects (e.g. reliability and quality of supply) are also crucial determinants, together with the type of energy sources (Pachauri & Spreng 2003).

Inequalities in energy provision and quality often represent a source of social injustice and other morality issues (UNDP 2005b). High disparities limit the opportunities of poor people and have severe social consequences that erode social capital (UNDP 2001). Within underprivileged communities, large

[23] Excluding endosomatic energy.

amounts of time and physical energy are spent on basic subsistence activities (Karekezi, Banda & Kithyoma 2002), such as gathering firewood. This enhances social marginalisation and limits the ability to improve living conditions. For example, access to modern energy can improve women's position in households and society by relieving them from some of the physically demanding chores of day-to-day existence (Holdren et al. 2000; Rehfuess, Mehta & Prüss-Üstün 2006). Similarly, modern lighting facilitates education of children. Energy also offers the possibility of pumping, boiling, disinfecting, purifying, storing and distributing water (IEA 2002). It thus helps provide drinking water and hygiene, water for domestic use and for irrigation.

The lack of fuel alternatives for cooking purposes can lead to significant environmental impacts in the case of scarcity of supply. If the natural production of the forest is overcome by the consumption of fuelwood for cooking and heating purposes, the natural capital can be depleted. The consequences are varied. There are greater distances to be travelled to collect fuel, and the associated services provided by the forest, such as the provision of food, diminish or disappear. Unfortunately in most, if not all, very poor countries or regions fuel alternatives for cooking and heating are either not available or not affordable (IISD 2004).

Healthcare can be improved and made more convenient by access to reliable energy services, for example, by allowing for the refrigeration of medication. Energy services can have direct influence in reducing maternal mortality and combating diseases (IEA 2002; Rehfuess, Mehta & Prüss-Üstün 2006). In addition, the use of traditional fuels for cooking and heating can have serious impacts on health. Indoor pollution caused by cooking fires affects mainly women and children as they are the most exposed to the toxic fumes (Holdren et al. 2000; Rehfuess, Mehta & Prüss-Üstün 2006).

Energy also facilitates productive activities and economic development. For instance, a more reliable access to energy services promotes agricultural development (IISD 2004), allowing for irrigation, better crop processing, storage, as well as transport to the market.

Most of the literature quantitatively assessing the link between energy and development considers development through the lens of economic growth and associated variables (see e.g., Ferguson et al. 2010; Lee 2005; Stern & Cleveland 2003; Toman et al. 2003). Other analysts consider a proxy of socio-economic development, such as the Human Development Index (HDI) (e.g., Najam & Cleveland 2003). Recent analysis provides empirical evidence suggesting a correlation between four distinct measures of development and energy access, focusing on HDI, poverty, education and child and maternal mortality (UNDP & WHO 2009).

The review of the literature highlights the challenge of explaining the complex interactions between energy and development (Toman, Jemelkova & Future 2003). It should be underlined here that a correlation does not prove a causal relationship. Especially in regard to development, numerous drivers are at play; attempts at figuring out the causality between energy and economic development provide mixed and conflicting results (see e.g., Lee 2005; Paul & Bhattacharya 2004). Pachauri et al. (2004) refer to the causal relationship between energy and development as being ambivalent. There is, however, no historical evidence of development and poverty reduction without expanding the use of energy (Saghir 2005) at macro level.

At household level however, there are instances whereby changes in energy patterns might lead to a reduction of energy use at the same time as delivering other benefits (e.g. developmental, environmental). For example, shifting from kerosene to efficient electric lighting considerably reduces energy use and increases the energy service. Also, shifting from solid biomass fuels to liquid or gaseous fuels similarly reduces energy use, though not as dramatically, while improving air quality and health.

2.2.2. The Millennium Development Goals and Energy

During the United Nations Millennium Summit held in New York in September 2000, world leaders adopted the Millennium Declaration (General Assembly 2000). The MDGs define developmental targets to be reached by 2015. Specifically, the goals provide key targets to address the most pressing development needs, and summarise the current main objectives of the development community. They are accompanied by a set of indicators that provide national data with regard to the status of various development proxies related to the achievement of the MDGs.

Even though none of the goals is energy-specific, and only one of the 60 indicators used to track the MDGs is energy specific (energy use per GDP), the importance of energy in meeting the target of halving poverty by 2015 is recognized by the international community. A key decision at the Ninth Session of the United Nations' Commission on Sustainable Development (CSD) underlined the urgent need of extending greatly the accessibility to energy services of the poor, especially in rural areas.

> *To implement the goal accepted by the international community to halve the proportion of people living on less than one dollar per day by 2015, access to affordable energy services is a prerequisite.* (CSD 2001, p. 9)

The role energy might play in regard to poverty alleviation and broader developmental objectives was stressed during the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg and clearly stated in the Plan of Implementation (JPOI):

> *Take joint actions and improve efforts to work together at all levels to improve access to reliable and affordable energy services for sustainable development sufficient to facilitate the achievement of the Millennium development goals* (WSSD 2002, p. 5)

There is considerable literature qualitatively describing the link between energy and the MDGs (i.e., DFID 2002; FEMA 2006; GNESD 2007; IEA, UNDP, and UNIDO 2010; McDade 2004; Modi et al. 2005; Rockstrom et al. 2005; UN-Energy 2005; UNDP 2005b) – see Annex 2-C. Still, recent analysis shows that much remains to be done to expand access to modern energy to facilitate the MDGs (UNDP & WHO 2009). Furthermore, it is not uncommon to find arguments that qualify the provision of energy as, "one of the most effective ways to achieve poverty alleviation" (GNESD 2007). Energy is even sometimes referred to as, "the missing MDG[24]". In a similar vein, Modi et al. (2005) argue that energy should be placed 'at par' with the MDGs.

The link between energy and development is widely described in qualitative terms in the literature, but rarely explore the object of explicit quantitative research thus far, particularly in the case of non-economic variables. This is particularly true in the case of the correlation between energy and the MDGs. Furthermore, the literature identifies the need for improving the information based related to energy access (UNDP & WHO 2009). This paper aims at addressing aspects of those shortcomings.

2.3. Methods

We apply statistical techniques to examine the correlation between selected energy indicators and indicators used to track progress towards the MDGs. The MDG framework is used with the objective of abstracting the complex relationships between energy and development. The MDGs indicators (see Annex 2-A) are cross-country, static data which are derived from the MDG Indicators database[25]. They are analyzed to explore the correlation with selected energy indicators Table 2-1.

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24 Reuters, 21 January 2009, http://www.reuters.com/article/idUSDEL270134._CH_.2400.

25 http://mdgs.un.org/unsd/mdg/.

Table 2-1: List of energy indicators

Indicator
Total final energy consumption
Total final electricity consumption
Energy intensity of the economy
Electrification rate
Share of access to modern fuels
Share of the population relying on solid fuels for cooking on improved cooking stoves

This data is based on the International Energy Agency database 2007 Edition, the World Energy Outlook Electricity Access Database[26], UNDP and WHO (2009) for the share of access to modern fuels and the share of the population relying on solid fuels, and the UN Statistics database[27] for population.

For each MDG goal, a composite index is created based on the respective MDG indicators (see Annex 2-A) for each MDG target. To do this, the score at country level is normalised in each indicator. The indicators for each target are combined using an equally-weighted additive model, using a simple yet transparent and intuitive aggregation method commonly applied in the field (e.g. HDI). In other words, an index is compiled by averaging the normalised score of a country in each relevant indicator for a given MDG target.

For the MDG indicators, we use the data series of 2005, since it is the most comprehensive set across the indicators at the time of writing. In the case where no data is available for a particular country for 2005, we apply a linear interpolation. If only data are available prior to, or after 2005, the closest available data is used as a best approximation. We disregard data prior to 1995. The analysis is limited to non-OECD countries.

The derived indexes are then compared with the energy indicators individually, rather than using a multivariate regression. Because the datasets are heterogeneous, a multivariate regression would be based on an insufficient amount of data points. Conversely, individual regressions provide insights based on more extensive data.

The datasets include outliers in some cases (see Figure 2-1 as an illustrative example). We use the method of Hadi (1992)[28] to identify those outliers. The countries featuring a disproportionately high energy consumption are likely to have a correlation between energy and development that is incomparable with other countries. Therefore, to avoid distorting the analysis, those few countries are not included in the regression analysis.

[26] http://www.iea.org/weo/electricity.asp.

[27] http://data.un.org/.

[28] Significance level for outlier cut-off : 0.01.

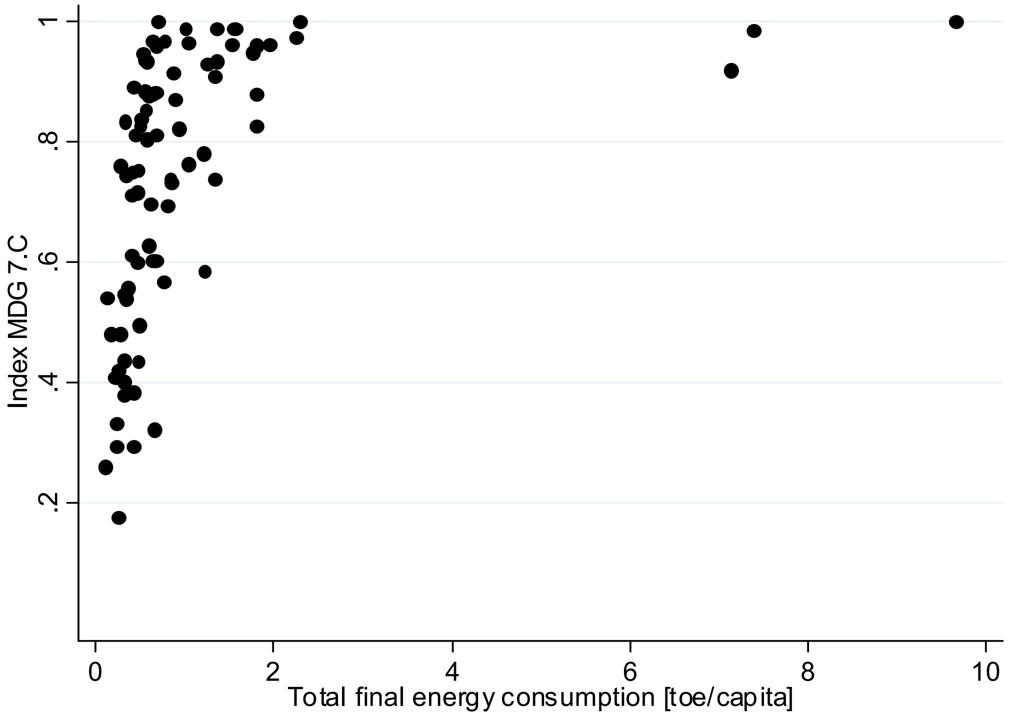

Figure 2-1: Scatter plot of the complete dataset of Total Final Energy Consumption with the MDG index on Drinking Water

Final energy consumption is used in this analysis rather than primary energy. Figures of total final energy consumption are not distorted by system (transmission and distribution) losses, which can be very high in some developing countries. Also, primary energy data rely on conversion factors for electricity generation, which alter the energy balance depending on the electricity mix. Focusing on final energy, however, does not avoid the effects of the difference in terms of energy efficiency at the end-use level between low-level and medium-level of development. For a number of reasons (affordability, access to information, etc.), the poorest are unlikely to be in a position to acquire energy-efficient appliances whereas slightly more developed communities might be able to use better equipment which require less energy input for a comparable or better service.

After these preliminary steps, we perform a regression analysis for each MDG target under the assumption that the relationship between development and energy is a non-linear, logarithmic-type curve. This assumption is based on a common practice in the literature described above. Also, from a development theory perspective, one can argue that at macro level an increase in the energy services is likely to be correlated with an improvement in a developmental aspect, but that the curve will flatten and eventually plateau once reaching a given level of energy service. In other words, the relationship is congruent with the concept of diminishing returns which is well documented (e.g., Najam and Cleveland 2003).

For the regression analyses, using the Ordinary Least Square[29] (OSL) approach, the energy indicator is considered as independent variable and the MDG index as dependent variable. The equation used in the analysis is of the following kind:

$$I_t = \beta_0 + \beta_1 \ln(E) \qquad \textbf{Equation 2-1}$$

[29] An analysis of the residuals shows signs of heteroscedasticity. Robust regressions are used by means of comparison with the results of the OLS regressions. The difference in the standard errors was found to be marginal. Therefore, the outcome of the analysis and major messages derived thereof are not altered significantly by the heterogeneity of the variance of the residuals.

where I_t is the MDG composite index of a given target t, E the energy indicator, β_1 the regression coefficient of the energy indicator E and β_0 the intercept. For the instances were less than 35 data points were available, the regression analysis was not carried out.

Aspects of energy demand are dependent on climatic conditions. To assert the influence of the climate on this analysis, we carried out the same analyses using two dependent variables: the MDG index and a dummy variable. The dummy variable consists of the latitude of the capital city of the countries which is used as a, arguably coarse, proxy for climatic conditions. We find that the influence of the climate is not conclusive in this sensitivity analysis: β_{clim}=0.08 (0.10). This implies that the findings of the analysis without including the climatic variable are robust from that viewpoint and that the outcome would not be influenced significantly if such factor was controlled for.

2.4. Results

Annex 2-B provides an overview of the regression coefficients and respective standard errors, coefficients of determination, and the sample sizes for each MDG target across all energy indicators assessed. A double and single asterisk indicates the coefficients statistical significance of 99% and 95%, respectively. Consequently, the absence of asterisk indicates that it is not possible to assert with sufficient confidence whether the correlation is positive or negative.

The predictor (the energy indicator) explains a substantial part (>0.35) of the variation in the response variable for a number of MDG targets (e.g. *Employment*, *Hunger*, *Education*, *Child mortality*, *Maternal health*, *Reproductive health*, and *Drinking water*) when assessed against the following energy indicators: *Total final energy consumption*, *Total final electricity consumption*, *Electrification rate*, and *Access to modern fuels*. The correlation coefficient is relatively low for the other MDG indexes. The regression curve of the energy indicators *Energy intensity* and *Use of improved cook stoves* correlated weekly with most development proxies.

Figure 2-2 provides examples of a strong and a weak correlation. Concretely, in the case of the regression between *Electrification rate* and *Drinking water* (MDG 7.C), the model accounts for 74 % of the variability in the dataset, whereas this proportion reaches only 10 % for the regression curve illustrating the correlation between *Electricity consumption* and *Poverty* (MDG 1.A).

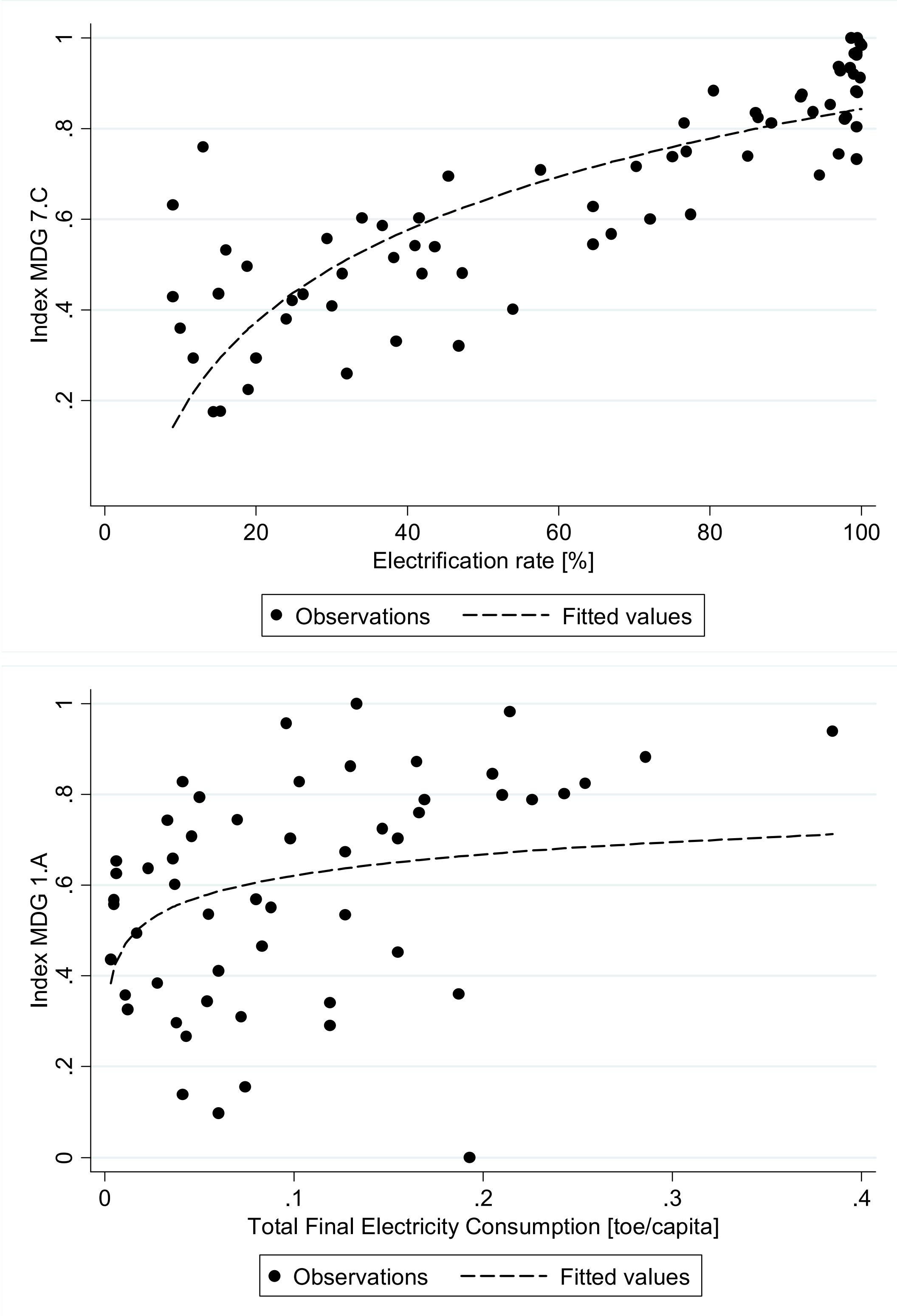

Figure 2-2: Instances of strong (R^2=0.74) and weak (R^2=0.10) correlation between *Electrification Rate* and the MDG index on *Drinking Water* (top panel), and *Final Electricity Consumption* and the MDG index on *Poverty* (bottom panel), respectively.

More importantly, the regression coefficient β_1 provides interesting insights on the linkages between energy and development. Specifically, β_1 represents the change in the MDG target that corresponds to a change in the energy indicator of a factor of 2.72 (e). In other words, the higher the coefficient β_1, the higher the change in the MDG indicator for a given incremental change in the energy indicator. For instance, country A consumes x amount of total final energy and has an index of y for MDG 1.A. Assuming the model is a perfect representation of reality, country B consuming 2.72x would therefore feature an index of y + 0.22. Figure 2-3 shows the regression coefficients for all MDG targets for *Energy* and *Electricity consumption*.

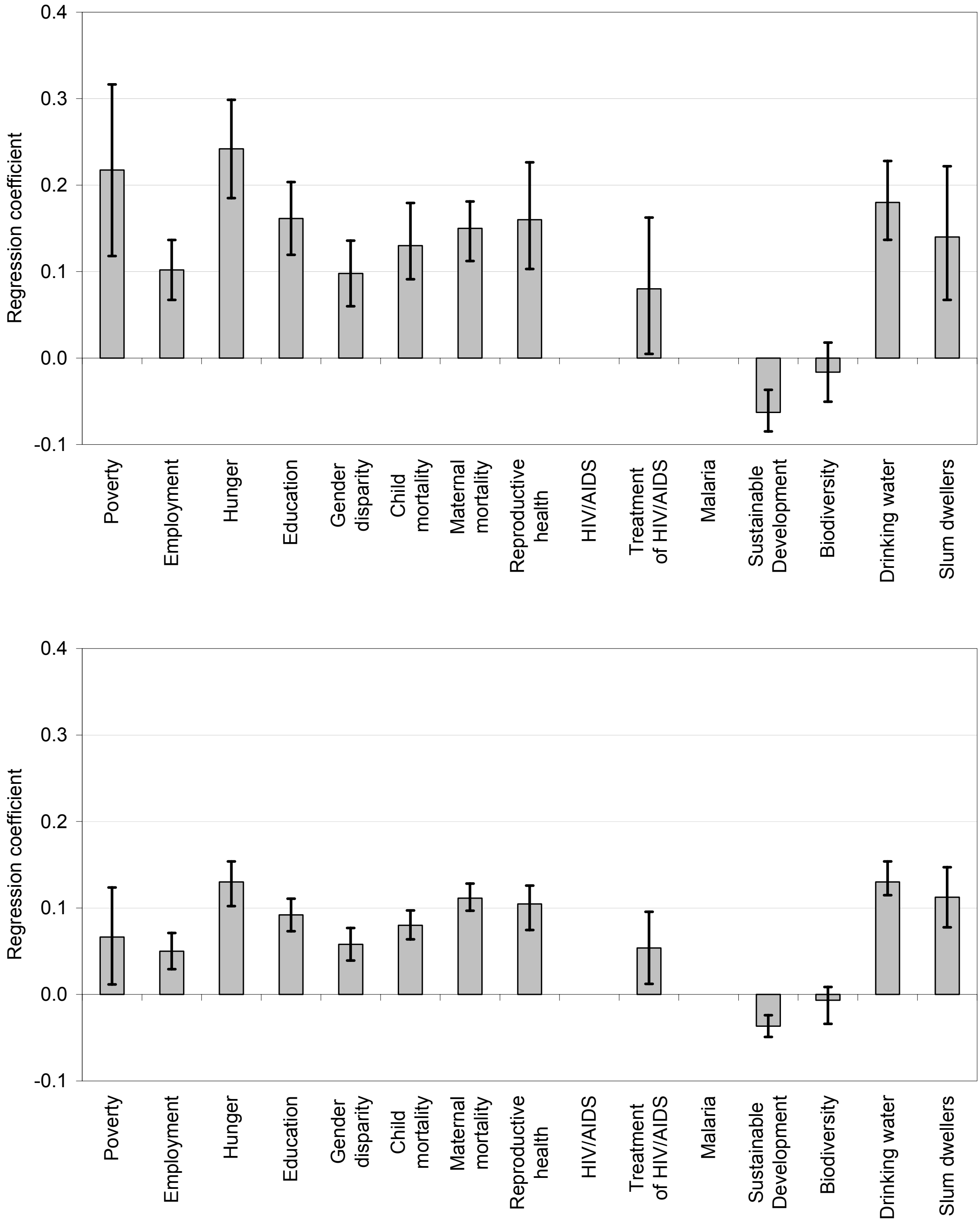

Figure 2-3: Corresponding change in MDG Index considering an incremental increase of *e* of the *Total Final Energy Consumption* (top panel) and *Total Final Electricity Consumption* (bottom panel). Error bars show the upper and lower bounds of the 95% confidence level.

This statistical analysis shows that the extent to which energy matters to different developmental aspect varies significantly. Indexes such as *Hunger* and *Drinking water* consistently feature high regressions coefficients. Conversely, the index on *Gender disparity* features lower, yet positive, β_1. By contrast, the correlation with the index on the *Integration of sustainable development principles into country policies* is negative, implying that an increase in energy consumption is at odds with sustainable development as characterised in the MDG indicators (per capita CO_2 emissions, consumption of ozone-depleting substances, and proportion of total water resources used).

The *Total energy consumption* seems to have a significant influence on the *Poverty* indicator, whereas *Total final electricity consumption* less so. This finding supports the call for an integrated approach to energy with regard to poverty alleviation that includes, but is not limited to, electricity. This analysis indicates that the combination of electricity with other forms of energy is particularly important for the proportion of people whose income is less than 1 dollar a day.

The correlation coefficients for the energy indicator on the *Electrification rare* and the *Share of access to modern fuels* are featured in Figure 2-4.

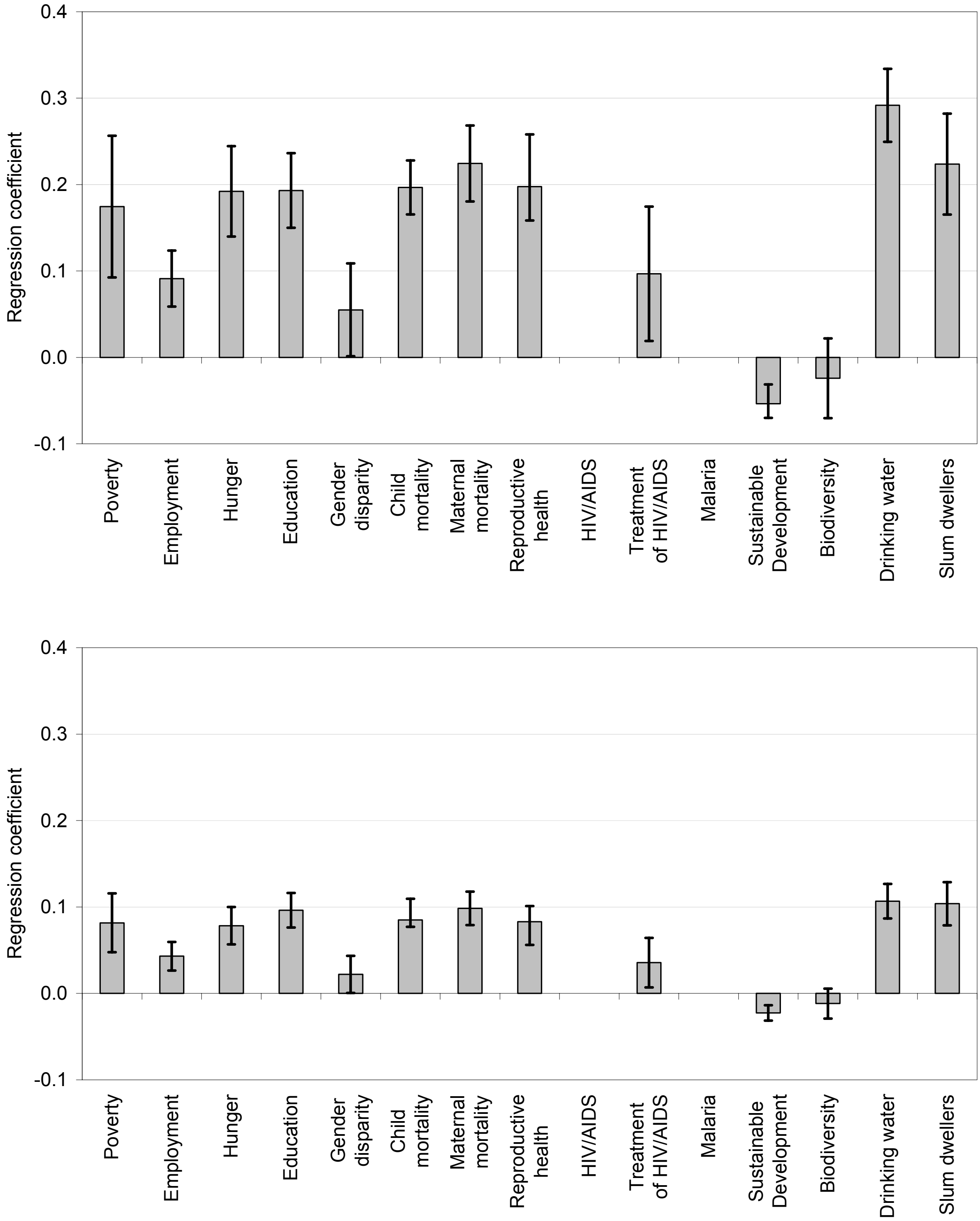

Figure 2-4: Corresponding change in MDG Index considering an incremental increase of e of the Electrification Rate (top panel) and Share of Access to Modern Fuels (bottom panel). Error bars show the upper and lower bounds of the 95% confidence level.

The highest correlation coefficient with regard to *Electrification rate* pertains to the MDG index on *Drinking water*, thus providing a clear link between access to electricity in regard to using improved drinking water sources and improved sanitation facility. Similarly, the regression coefficients for *Child and maternal mortality*, as well as *Reproductive health*, are consistently high, supporting the claim that modern energy is crucial to a functioning health system. On the other hand, the index on *Employment* is less sensitive to a change in either the *Electrification rate* or the *Access to modern fuels* indexes. No conclusive insights can be deduced from this analysis in regard to *Gender disparity*, *HIV/AIDS* and *Malaria* related indexes due to the weak correlation.

2.5. Discussion

We note that the scope of the analysis is restricted to the study of the linkages between energy and selected developmental issues. There is no attempt in this paper to discuss strategies to address under-development with the provision of energy; this could be the object of further research. The paper does not discuss the various global issues (e.g. health, poverty, gender inequalities) in detail. The objective of this analysis is to shed light of the correlation between energy and development.

In general, the outcomes of this analysis should be interpreted with caution for a number of reasons. Foremost, and as underlined in the literature, the information base is patchy in some cases. For some indicators the time series are sparse. Also, some data represent extrapolations of samples, sometimes complemented by modelling where data is lacking. One method to obtain samples commonly applied is through censuses and surveys, also raising issues of comparability in some cases. With regard to the energy indicators, while there is significant confidence in the data on energy consumption, there is still room for improvement in compiling consistent datasets for other energy indicators.

It must be noted here that IEA data include only so-called commercial energy. The purpose of this research is to inform policies that are geared towards promoting access to energy services based on modern, and thus commercial energy carriers. It is acknowledged however, that traditional biomass energy plays a significant role, particularly so in impoverished communities. However, considering the linkages between aspects related to the use of traditional biomass and development goes beyond the scope of this paper.

Also, it must be underlined that the access to modern energy carriers is a necessary, but not sufficient condition for poverty alleviation and economic development. Indeed, beside affordable energy carriers, an access to end-use devices to transform the carrier in to various energy services is requisite. Along those lines, the inclusion of the energy indicator on the availability of improved cooking stoves is an attempt to capture such dimension.

The analysis is carried out at national level. One can reasonably expect aggregated data to mask significant local disparities. The approach at national level is justifiable in that it allows for inter-countries comparison with available datasets. However, there are reasons to believe that the little insight that can be derived from this analysis with regard to some developmental aspects, gender disparity notably, might be due to the methodology applied and the data paucity rather than to the absence of correlation. The same might hold for the correlation with the energy indicator on the use of improved cooking stoves. Specific case studies at a finer geographical scale would provide additional, complementary information.

In addition to this, the analysis carried out is static. In other words, it provides a snapshot of the correlation between energy and development at a given time. It does not however grasp the dynamic nature of the relationship between energy and development, nor does it give any indication on the feasibility of achieving the MDGs. In an effort to include the time variable, we carried out a similar statistical analysis with gradients for both energy and MDG indicators based on time series. We did not find results that are statistically significant and therefore do not report on this analysis. We however note that such aspects deserve further work.

2.6. Conclusion

This analysis is aimed at improving the understanding of the specific links between energy and development. To this end, we provide an articulation of the correlation between energy and the MDGs. The paper does not address specific global issues in detail and refers to the specific literature on the respective subjects.

Our main findings are as follows:

Goal 1: Eradicate extreme poverty and hunger. Energy is generally relatively well correlated with poverty, employment and hunger. The regression coefficient is particularly high between energy consumption and the poverty and hunger dimensions. Interestingly, energy consumption appears to be more relevant than electricity consumption alone in some instances, in particular for poverty. This finding questions initiatives solely geared towards electrification, and calls for a more integrated approach towards enhancing access to a wide range of energy services to alleviate poverty.

Goal 2: Achieve universal primary education. Education is also well correlated with energy and electricity consumption, as well as with electrification rate and access to modern fuels. This finding supports the claim that an access to modern energy facilitates school enrolment and completion thereby improving the literacy rate.

Goal 3: Promote gender equality and empower women. The correlation between energy and gender is found to be relatively weak. This analysis provides only feeble evidence that energy contribute to women emancipation. It must be noted that the level of aggregation of the analysis could possibly to be masking a stronger correlation at a finer scale.

Goal 4; 5; and 6: Reduce child mortality; Improve maternal health; and Combat HIV/AIDS, malaria and other diseases. Child and maternal mortality, as well as reproductive health, are relatively well correlated with the energy. In particular, access to modern fuels and the use of improved cooking stoves feature the highest regression coefficients with the child and maternal mortality dimensions, thereby supporting the common argument that the use of traditional biomass adversely impact women and children's health due to indoor pollution from incomplete combustion notably. This analysis provides no evidence however of the relationship between energy and other health matters, such as HIV/AIDS and malaria.

Goal 7: Ensure environmental sustainability. The correlation between energy and the sustainable development index is of negative nature for all energy indicators. Promoting energy access under the current dominating paradigm seems to go at odd with promoting environmental sustainability, as interpreted by the MDG indicators. Beside this, there is a strong, positive correlation between energy and access to safe drinking water.

Our statistical analysis reaffirms a generally positive influence of access to energy services on development. It also, however, challenges claims of its universally positive benefits to specific development priorities. The regression analyses suggest a strong correlation between energy and numerous development indicators (e.g. *Poverty*, *Hunger*, *Drinking water*), and weak correlation with others (e.g. *Biodiversity*, *Gender disparity*).

Further research could include analysis at a more disaggregated level. Indeed, focusing on specific strata of the population and/or assessing the issue at sub-national level would provide additional, complementary insights. The data paucity is, however, a major barrier to such efforts. Albeit the relatively coarse nature of the analysis presented in this paper, it contributes to the literature by helping to add some level of granularity and identifying gaps.

One could argue that the promotion of access to energy services by development assistance makes particular sense if the developmental objectives are focused on those that feature a strong correlation with energy. For instance, this analysis indicates that actions geared towards improving energy access are likely to be especially beneficial with regard to drinking water, hunger, and poverty notably. This insight may be able to help policy makers to create more effective interventions.

Acknowledgments

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Annex 2-A: Indicators used in the respective MDG indexes

	Target	Indicators	*
1.A	Halve, between 1990 and 2015, the proportion of people whose income is less than on dollar al day	Proportion of population below national poverty line	-
1.B	Achieve full and productive employment and decent work for all including women and young people	Growth rate of GDP per person employed	+
		Employment-to-population ratio[30]	+
		Proportion of employed people living below $1 (PPP) per day	-
		Proportion of own-account and contributing family workers in total employment	-
1.C	Halve, between 1990 and 2015, the proportion of people who suffer from hunger	Prevalence of underweight children under-five years of age	-
		Proportion of population below minimum level of dietary energy consumption	-
2.A	Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling	Net enrolment ratio in primary education	+
		Proportion of pupils starting grade 1 who reach last grade of primary	+
		Literacy rate of 15-24 year-olds, women and men	+
3.A	Eliminate gender disparity in primary and secondary education, preferably by 2005, and in all levels of education no later than 2015	Ratios of girls to boys in secondary education	+
		Share of women in wage employment in the non-agricultural sector	+
		Proportion of seats held by women in national parliament	+
4.A	Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate	Under-five mortality rate[31]	-
		Infant mortality rate	-
		Proportion of 1 year-old children immunised against measles	+
5.A	Reduce by three quarters, between 1990 and 2015, the maternal mortality ratio	Maternal mortality ratio	-
		Proportion of births attended by skilled health personnel	+
5.B	Achieve, by 2015, universal access to reproductive health	Contraceptive prevalence rate[32]	+
		Adolescent birth rate	-
		Antenatal care coverage (at least four visits)	+
		Unmet need for family planning	-

[30] The reliability of this dataset is questionable. It correlates negatively with the others. The nature of the correlation does not change significantly if this variable is omitted in the analysis: Energy: β1=0.17 (0.03), and Electricity: β1= 0.1 (0.01).

[31] The correlation between *Under-five mortality rate* and *Infant mortality rate* is strong (0.98). Therefore, only *Infant mortality rate* is used alongside *Proportion of 1 year-old children immunised against measles.*

[32] The correlation between *Contraceptive prevalence rate* and *Unmet need for family planning* is strong (0.80). Therefore, only *Unmet need for family planning* is used the other variables.

	Target	Indicators	*
6.A	Have halted by 2015 and begun to reverse the spread of HIV/AIDS	HIV prevalence among population aged 15-24 years	-
		Condom use at last high-risk sex (women)	+
		Proportion of population aged 15-24 years with comprehensive correct knowledge of HIV/AIDS (men)	+
		Ratio of school attendance of orphans to school attendance of non-orphans aged 10-14 years	+
6.B	Achieve, by 2010, universal access to treatment for HIV/AIDS for all those who need it	Proportion of population with advanced HIV infection with access to antiretroviral drugs	+
6.C	Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases	Proportion of children under 5 sleeping under insecticide-treated bednets	+
		Proportion of children under 5 with fever who are treated with appropriate anti-malarial drugs	+
		Death rates associated with tuberculosis	-
		Proportion of tuberculosis cases detected and cured under directly observed treatment short course	+
7.A	Integrate the principles of sustainable development into the country policies and programmes and reverse the loss of environmental resources	Proportion of land area covered by forest[33]	+
		CO_2 emissions, total, per capita and per $1 GDP (PPP)	-
		Consumption of ozone-depleting substances	-
		Proportion of total water resources used	-
7.B	Reduce biodiversity loss, achieving, by 2010, a significant reduction in the rate of loss	Proportion of terrestrial and marine areas protected	+
7.C	Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation	Proportion of population using an improved drinking water source	+
		Proportion of population using an improved sanitation facility	+
7.D	By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers	Proportion of urban population living in slums	-

* The sign refers to indicators positively (+) and negatively (-) correlating to development. This property is used to compute the composite index.

[33] Cannot be used as proxy for cross-country comparison and therefore disregarded from the analysis.

Annex 2-B: Results of the regression analyses for the respective MDG targets

		Total Final Energy Consumption			Total Final Electricity Consumption			Energy Intensity			Electrification Rate			Share of Access to Modern Fuels			Share of the Population Using Improved Cooking Stoves		
	Target	β_1	R^2	n	β_1	R^2	n	β_1	R^2	n	β_1	R^2	n	β_1	R^2	n	β_1	R^2	n
1.A	Halve, between 1990 and 2015, the proportion of people whose income is less than on dollar al day	0.22** (0.05)	0.27	54	0.07* (0.03)	0.10	54	-0.06 (0.05)	0.03	55	0.17** (0.04)	0.30	45	0.08** (0.02)	0.30	57	0.05 (0.03)	0.07	40
1.B	Achieve full and productive employment and decent work for all including women and young people	0.10** (0.02)	0.46	44	0.05** (0.01)	0.36	44	-0.11** (0.03)	0.27	41	0.09** (0.02)	0.48	37	0.04** (0.01)	0.42	40	0.04* (0.01)	0.22	27
1.C	Halve, between 1990 and 2015, the proportion of people who suffer from hunger	0.24** (0.03)	0.51	71	0.13** (0.01)	0.58	71	-0.12** (0.04)	0.12	74	0.19** (0.03)	0.44	69	0.08** (0.01)	0.38	85	0.07** (0.02)	0.21	57
2.A	Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling	0.16** (0.02)	0.47	68	0.09** (0.01)	0.58	70	-0.09** (0.02)	0.15	71	0.19** (0.02)	0.57	62	0.10** (0.01)	0.56	75	0.04* (0.02)	0.09	45
3.A	Eliminate gender disparity in primary and secondary education, preferably by 2005, and in all levels of education no later than 2015	0.10** (0.02)	0.27	73	0.06** (0.01)	0.35	74	-0.03 (0.02)	0.02	77	0.06* (0.03)	0.06	66	0.02* (0.01)	0.04	87	0.03* (0.01)	0.13	47
4.A	Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate	0.13** (0.02)	0.35	82	0.08** (0.01)	0.51	85	-0.08** (0.02)	0.13	87	0.20** (0.02)	0.59	77	0.08** (0.01)	0.44	111	0.03 (0.02)	0.05	60
5.A	Reduce by three quarters, between 1990 and 2015, the maternal mortality ratio	0.15** (0.02)	0.46	87	0.11** (0.01)	0.71	87	-0.11** (0.03)	0.14	86	0.22** (0.02)	0.58	76	0.10** (0.01)	0.51	101	0.05** (0.02)	0.13	59
5.B	Achieve, by 2015, universal access to reproductive health	0.16** (0.03)	0.41	43	0.10** (0.01)	0.60	43	-0.04 (0.04)	0.02	45	0.20** (0.02)	0.64	41	0.08** (0.01)	0.51	49	0.03 (0.02)	0.04	35
6.A	Have halted by 2015 and begun to reverse the spread of HIV/AIDS			18			18			19			20			25			18
6.B	Achieve, by 2010, universal access to treatment for HIV/AIDS for all those who need it	0.08* (0.04)	0.06	68	0.05* (0.02)	0.09	68	-0.15** (0.03)	0.22	67	0.10* (0.04)	0.09	62	0.04* (0.01)	0.07	79	0.03 (0.02)	0.05	55
6.C	Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases			18			18			19			20			33			29

		Total Final Energy Consumption			**Total Final Electricity Consumption**			**Energy Intensity**			**Electrification Rate**			**Share of Access to Modern Fuels**			**Share of the Population Using Improved Cooking Stoves**		
	Target	β_1	R^2	**n**	β_1	R^2	**n**	β_1	R^2	**n**	β_1	R^2	**n**	β_1	R^2	**n**	β_1	R^2	**n**
7.A	Integrate the principles of sustainable development into the country policies and programmes and reverse the loss of environmental resources	-0.06** (0.01)	0.25	78	-0.04** (0.01)	0.31	78	0.02 (0.01)	0.03	78	-0.05** (0.01)	0.30	65	-0.02** (0.00)	0.23	86	-0.01** (0.00)	0.18	55
7.B	Reduce biodiversity loss, achieving, by 2010, a significant reduction in the rate of loss	-0.02 (0.02)	0.01	91	-0.01 (0.01)	0.02	91	0.00 (0.02)	0.00	87	-0.02 (0.02)	0.01	77	-0.01 (0.01)	0.02	109	-0.01 (0.01)	0.01	60
7.C	Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation	0.18** (0.02)	0.45	80	0.13** (0.01)	0.71	81	-0.13** (0.03)	0.17	77	0.29** (0.02)	0.74	69	0.11** (0.01)	0.52	105	0.05* (0.01)	0.10	60
7.D	By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers	0.14** (0.04)	0.20	59	0.11** (0.02)	0.42	59	-0.14** (0.04)	0.16	59	0.22** (0.03)	0.47	67	0.10** (0.01)	0.44	87	0.04 (0.02)	0.05	56

** statistically significant at 99%; * statistically significant at 95%

Blanks indicate that not sufficient data (n<35) was available for the regression analysis.

Annex 2-C : Qualitative description of the link between energy

Goal 1: Eradicate extreme poverty and hunger. Energy can facilitate economic development by providing the means for productive activities, beyond daylight hours, thus enhancing the creation and development of businesses thereby promoting local employment. Also, most staple food needs cooking. Furthermore, energy allows for water pumping, as well as for increasing agricultural yields through use of machinery and irrigation.

Goal 2: Achieve universal primary education. Children commonly spend significant time on basic survival activities, such as gathering fuelwood, fetching water, and cooking in impoverished communities. Access to modern energy frees time up and allows children to go to school. Also, electricity is important for education because it permits access to information (e.g. radio) and communication technology. Similarly, lighting allows for studying. In remote settlements, electricity availability also facilitates retaining teachers.

Goal 3: Promote gender equality and empower women. Women spent considerable time on basic subsistence activities. The availability of modern energy carriers facilitates other activities, productive activities, and social interactions and emancipation.

Goal 4; 5; and 6: Reduce child mortality; Improve maternal health; and Combat HIV/AIDS, malaria and other diseases. Energy seems crucial for a functioning health system. It allows for the conservation of medications and vaccinations, facilitates sterilization, and provides for better medical facilities for maternal care. It permits pumping and filtering water. Most importantly, modern energy reduces indoor pollution from incomplete combustion in inefficient cooking stoves.

Goal 7: Ensure environmental sustainability. Modern energy can relieve the pressure put on the environment by the unsustainable use of biomass. Energy efficiency is increased by using improved cooking stoves. Also, the promotion of the use of renewable energy, unlike fossil fuel based energy, is congruent with the protection of the environment locally and globally. By improving agricultural productivity, the pressure to further expand exploited land is reduced. The unsustainable exploitation of ecosystem for fuelwood causes deforestation, soil degradation and erosion, thereby reducing the soil fertility. Using cleaner energy also reduces greenhouse gas emissions and the impact on the climate system.

Goal 8: Develop a global partnership for development. Trade and international cooperation have proved vital to energy development and supply. Cooperative mechanisms can assist in making use of resources and be key in lowering energy costs and thus improving accessibility.

Note: compiled from DFID 2002; FEMA 2006; GNESD 2007; IEA, UNDP, and UNIDO 2010; McDade 2004; Vijay Modi et al. 2005; J. Rockstrom et al. 2005; UN-Energy 2005; UNDP 2005b.

3. Measuring Energy Poverty: Focusing on What Matters

3.1. Introduction and context

Energy is central to addressing many of today's global development challenges, including poverty, inequality, climate change, food security, health and education. The link between energy and the Millennium Development Goals (MDGs) has been discussed extensively in the literature (see e.g., Modi et al. 2005) and energy poverty is undermining their achievement.

Current actions to eradicate energy poverty are falling short both in terms of scale and pace. In fact, if current trends continue, more people will be without modern energy access in 2030 than currently ((IEA, UNDP & UNIDO 2010). Changing this pathway requires global political commitment that goes beyond abstraction and sets out actions and associated benchmarks (Bazilian, Nussbaumer, Cabraal, et al. 2010). A goal of providing universal access to modern energy services has recently been put forth to the international community (AGECC 2010). The current lack of quality data will hamper this effort.

The development of tools to support the monitoring and reporting of progress towards widespread energy access is thus instrumental. This analysis reviews a series of specific metrics and examines the methodological strengths and shortcomings of various models. An analytical gap is addressed by laying the foundation for a novel composite index to measure energy poverty as a complement to existing tools. Initial results to demonstrate its applicability are also provided.

3.2. The use of indicators and composite indices

The use of indicators is widespread. Indicators are useful as proxies to quantify and analyse performance, and therefore provide valuable insights for policy analysis and design, as well as for wider communication. IAEA (2005, p. 2) reflected that, '…indicators are not merely data; rather, they extend beyond basic statistics to provide a deeper understanding of the main issues and to highlight important relations that are not evident using basic statistics. They are essential tools for communicating energy issues related to sustainable development to policymakers and to the public, and for promoting institutional dialogue.'

Bazilian et al. (2010) review a selection of metrics in the sustainable development and energy space. Three broad categories can be identified to classify the type of metrics: single indicators; set of individual, non-aggregated indicators (or 'dashboard'); and composite indices (see Table 3-1).

Table 3-1: Broad categories of sustainable development and energy metrics with examples

Category	Example	Initiator	Reference
Single indicator	International poverty line (1$ per day)	The World Bank	(Chen & Ravallion 2008)
Set of individual indicators, or 'dashboard'	Millennium Development Goals Indicators	UN	(UNSD, UNDESA & UN n.d.)
	Energy Indicators for Sustainable Development	IAEA	(IAEA 2005; Vera & Langlois 2007)
Composite indices	Human Development Index	UNDP	(UNDP 2010b)
	Energy Development Index	IEA	(IEA 2010b)

3.2.1. Precedents specific to energy poverty

This section provides a brief review of the existing literature on metrics that can be used to quantitatively assess energy poverty.

The Energy Indicators for Sustainable Development (EISD) provides definitions, guidelines and methodologies for the development and use of a set of energy indicators (IAEA 2005; Vera & Langlois

2007) (IAEA 2005, Vera and Langlois 2007). More specific to energy poverty, Foster et al. (2000) use three individual measures to quantify it, based on a pre-defined fuel poverty line. More recently, Mirza and Szirmai (2010) developed a new composite index to measure the degree of energy poverty among rural households in rural Pakistan. The Energy Development Index (EDI) is a composite measure of energy use in developing countries (IEA 2010b). The report 'Poor people's energy outlook 2010' (Practical Action 2010) suggests an energy access index based on six essential energy services for which a minimum level of service is prescribed. In parallel, it introduces a hybrid set of indicators that assign a numerical value to qualitative aspects of energy access in three main supply dimensions, namely household fuels, electricity and mechanical power.

3.2.2. Methodological insights

Precedents, both within and outside of the energy sector, have produced a rich set of lessons from which to draw on when considering developing a new metric to measure and report on energy poverty. A mix of statistical rigour, transparency, data availability, political attractiveness, simplicity, and usefulness for policy design is wishful. The section below discusses the strengths and weaknesses of various methodological aspects.

3.2.2.1. Uni- vs. Multi-dimensionality

Single indicators are straightforward to handle. They provide a powerful, unbiased message that is easy to interpret with regard to one specific dimension. On the other hand, such metrics present a narrow picture of the issue measured. While perhaps appropriate in some cases (e.g. measuring the level of economic activity with gross domestic product), single indicators are often unsuitable for less tangible issues, such as sustainable development or poverty.

Complex issues such as human development are multidimensional in their very nature. Their assessment therefore requires a framework in which various elements can be captured. A number of initiatives aim to provide a set of individual indicators. Such 'dashboards' depict a much more comprehensive representation of the issue at hand. For instance, the Millennium Development Goals Indicators programme helps track progress on the commitment made in the United Nations Millennium Declaration with a battery of over 60 indicators.

Nonetheless, evaluating changes in a large number of indicators and deriving meaningful insight is no easy task. Indeed, tracking trends over time, or carrying out cross-country comparison, based on a 'dashboard' of indicators might prove impracticable. Beside this, it is useful in some cases to quantify multiple attainments, such as the incidence of multiple deprivations. In such instances, there is no way to avoid resorting to some form of aggregation model.

As a compromise between the simplicity of uni-dimensional indicators and the need to account for the multidimensional nature of some issues, composite indices were created. They represent an attempt to overcome the shortcomings of one-dimensional indicators while at the same time produce an outcome that condenses the information to single, easy to interpret metrics.

3.2.2.2. Composite indices

Composite indices are single numerals calculated from a number of variables that represent the aggregated value of a dimension that in itself might be elusive (e.g. sustainable development) on the basis of an underlying model. Based on a set of sub-indicators that might or might not have a common unit of measurement, they aim to capture the multidimensional aspects of an issue that cannot be depicted in a single indicator. The lack of common unit does not imply incomparability. Multi-criteria theory provides tools to overcome issues related to incommensurability (Martinez-Alier, Munda & O'Neill 1998).

Composite indices have been widely used as an alternative to single, uni-dimensional values. The rationale for developing composite indices lies in the need for aggregating information to a level that makes analysis convenient. They have proven to be useful for benchmarking performance, for example between countries. A large number of institutions are producing composite indices in a wide variety of research problems and fields (OECD 2008). A list of examples is available in Saisana and Tarantola (2002).

The drawback of composite indices is that, by combining variables, the process includes some form of reduction to a single measure, with all the associated methodological issues and required assumptions and simplifications it implies (including value judgments). Composite indices can be misleading in terms of policy, particularly in the case whereby the analysis of the results is too simplistic and/or when the indicator is poorly constructed. In that regard, Ravallion (2010) underlines the common gap between the theoretical ideal and practical measurement.

Various publications have underlined the lack of theoretical underpinning of a number of composite indices (e.g., Saisana and Tarantola 2002; Freudenberg 2003; Munda and Nardo 2005), highlighting issues related to the aggregation model and/or the weightings in particular. The Human Development Index (HDI), arguably the most influential metric of human development, and other similar composite indices have been widely criticised in the development literature for inconsistencies, methodological flaws and redundancy (McGillivray 1991; Noorbakhsh 1998; Morse 2003; Hoyland, Moene & Willumsen 2009; UNDESA 2009). As a result of these critiques, the methodology to compile the HDI has changed a number of times over the years. Symptomatic of various views amongst experts in the field is also the recent heated discussion between the 'aggregators' and 'non-aggregators' triggered by the launch of the Multidimensional Poverty Index (MPI) in the 2010 Human Development Report (see UNDP 2010).

Different aggregating methods are available for the design of a composite index (for review and description, see e.g., Zhou et al. 2006). Commonly used is the simple additive method, or weighted sum. This model has been widely applied for its transparency and ease of use, including by non-experts. An alternative to the weighted sum is the weighted geometric mean aggregation. Ebert and Welsch (2004) see advantages in using such a model but also note its limitations. Other, more advanced approaches deriving from multi-criteria decision analysis are commonly more complicated to compute and the interpretation of the results is less intuitive.

3.2.2.3. The issue of weight and compensability

The issue of weight is somewhat controversial. One can argue that all criteria considered in an index need not necessarily have the same relative importance or symmetrical importance (in the jargon of decision theory literature). However, theoretically-sound frameworks to derive rational weighting approaches are difficult to construct (Freudenberg 2003). Assigning weights can be challenging and is an arbitrary and value-driven process. Some have suggested participatory methods for this purpose. However, consensus over the relative importance of various dimensions is challenging, particularly in the case of conflicting objectives. Having noted this, the process of including or excluding criteria, even without weight, is a value judgment per se on the relative importance of the variables.

In the case of compensatory frameworks, such as additive models, critics argue that using weights to embody intensity of importance represents a theoretical inconsistency (Munda 2008). Indeed, in the case of linear compensatory aggregation models, weights depend on the measurement scale of the criteria and are to be interpreted as trade-offs, or judgements about compensability, and not as importance factors (Munda & Nardo 2005). In line with this thinking, the aggregation procedure needs to be non-compensatory where weights are used with the meaning of importance coefficients.

3.2.3. Synthesis

The use of indicators and indices is widespread. However, some concepts, such as sustainable development, are relatively intangible in nature and therefore more challenging to characterize and quantify. Composite indices have been developed as an attempt to capture multidimensionality and/or multiple attainments. Yet, the methodological soundness of some of those indices has been questioned on a number of grounds. This notwithstanding, one can argue that composite indices provide a useful statistical summary of particular issues, bearing in mind their limitations.

There are clear trade-offs in the choice of the aggregation model, notably in terms of loss of information, level of compensability allowed between variables, and ease of use and transparency. Ultimately, the selection of the appropriate method depends primarily on the objective of the index and the target audience.

A hybrid approach would consist of an aggregated set of indicators that are monitored and reported upon individually alongside a composite index which captures the essence of the concept being evaluated. It can reconcile the advantages of a single, easy-to-understand and -interpret composite metric, acknowledging its crude and imperfect nature, with the benefits of providing more detailed information. A wealth of literature (UNDESA 2001; Saisana & Tarantola 2002; Freudenberg 2003; OECD 2008), from which this analysis draws, provides useful insights for the development of metrics in general and composite indices in particular.

3.3. The Multidimensional Energy Poverty Index (MEPI): A new metric to measure and report on energy poverty

The provision of detailed and accurate information on energy poverty has the potential to positively influence the design of policy, regulatory and financial strategies to address the issue. A new metric to measure and report on energy poverty to fill an analytical gap is described herein. As a starting point, we underline the multidimensional nature of energy poverty, and the need to capture a range of various elements to adequately reflect the complexity of the nexus between access to modern energy services and human development. A multi-criteria framework therefore appears ideally suited. Also, a composite index is suggested as a means of capturing multiple deprivations. Noting the issues related to the use of composite indices, selected individual indicators are reported upon.

In contrast to other tools, the focus lies on quantifying energy deprivation, as opposed to energy access. A number of indices include consumption-based indicators under the assumption that energy consumption is correlated to development. While recognising the value of such conglomerative approaches, a deprivational perspective offers a valuable complement by focusing specifically on the poor (Anand & Sen 1997), thereby providing a more direct indication of the relevant aspects of poverty.

In addition, one must note the relatively limited attention that has been devoted to capturing aspects related to the quality of the energy services delivered and/or their reliability, as well as to the notion of affordability. More importantly, an ideal energy poverty metric should shed light on the issue through the lens of the energy services, which is ultimately what is of importance to people and makes a difference in their lives. Also, most metrics are primarily focused on the supply side or input-oriented data; a better tracking of demand-side elements is desirable. Finally, the algorithm of the metric should ideally be able to accommodate variables of various kinds, like cardinal and ordinal (categorical). Indeed, in the case of an energy poverty metric, some variables are likely to be qualitative, such as the type of fuel used.

3.3.1. Energy poverty: delimiting the scope

There are a number of attempts to quantitatively define energy poverty (e.g., Foster et al. 2000; UNDP 2000; IEA 2010; Practical Action 2010). Such estimations, however, rest on a set of arbitrary assumptions with regard to the consuming energy devices as well as a normative definition of what a set of basic needs consist of (Pachauri & Spreng 2003). Also, the quantification of basic needs is contingent to the context (cultural practices, climatic conditions, etc.). Beside levels of energy consumed, various analysts have underlined the importance of the type of energy sources accessible (Pachauri & Spreng 2003) as well as the quality of the supply (Practical Action 2010).

For the purpose of this study, the scope is limited to household needs exclusively, while acknowledging that other energy needs exist for a society to develop and thrive. Common energy services demanded in households include: cooking, space heating/cooling, lighting, entertainment/education (radio, TV, computer), services provided by means of household appliances (e.g. refrigerator, washing machine, and electric geyser), telecommunications, and mechanical power.

3.3.2. Data availability

Any energy poverty metric is likely to be constrained by data paucity. It is therefore necessary to map and review the data that could serve to underpin a measure of energy poverty.

As an example of possible sources, the International Energy Agency (IEA) has been compiling data on energy access at national level since 2004. While some datasets are available in the public domain, others are only accessible through subscription or not at all (e.g. time series). Another source is the MEASURE DHS (Demographic and Health Surveys) project, funded by the United States Agency for International Development (USAID). It is collecting and disseminating nationally representative data on a range of issues such as fertility, family planning, maternal and child health, gender, HIV/AIDS, malaria, and nutrition. Based on household surveys, the information gathered includes a number of indicators related to energy poverty. UNICEF Childinfo reports on similar indicators. Datasets from both sources are available in raw format (output of surveys), as well as in treated form (at national level) for selected indicators.

The great advantage of data based on surveys, from the perspective of energy poverty, is that it provides, beside information on energy related issues, a context. This allows, for instance, decomposition and detailed analysis at sub-national level, by urban vs. rural populations, by level of income/spending, etc, which provides valuable insights of high relevance with regard to the development of customised measures and policies.

Focusing on the deprivation of the services energy provides brings about new challenges with regard to identifying indicators and the availability of data. Quantifying the deprivation in some energy services, such as mechanical power or lighting, might benefit from the use of proxy indicators. Indeed, no comprehensive set of data exists on adequate lighting in households for instance. The choice of the proxy entails some normative judgment, and it is crucial to ensure that it is closely correlated with the service to be quantified. Yet, the use of proxies represents a potentially powerful way to explore new grounds in terms of quantifying energy poverty.

3.3.3. Identifying and developing a set of relevant variables

The multidimensional nature of energy poverty should be reflected in the choice and structure of the variables. The variables should be carefully selected on the basis of their relevance to the issue at hand and measurability (including availability of sufficient and reliable data). The analysis is based on data from the Demographic and Health Surveys (DHS) (MEASURE DHS n.d.) as they provide the most comprehensive datasets for the purpose of this analysis. The different dimensions of the new energy metric are defined around commonly demanded household energy services to capture various elements as discussed below.

Cooking is amongst the very basic needs. Energy, in the form of heat, is required to prepare meals. Elements of energy poverty related to cooking are captured by including the type of fuel used, keeping the notion of convenience in mind. That is, evidence shows that a significant time is spent, mainly by women and children, for daily chores, including collecting fuel for cooking. The use of so-called traditional fuels (firewood, charcoal, dung, etc.) has an important opportunity cost compared to more 'modern' fuels. Also, indoor pollution from incomplete combustion represents a major health issue. Therefore, the type of stove used (with or without hood/chimney) is used as an imperfect proxy to capture those aspects.

Taking into consideration the limitations on data availability, space heating/cooling is not considered in the algorithm developed. Nevertheless, a correlation between the desirable indicators related to space heating and those related to cooking can be suspected. Indeed, the type of fuel and device are bound to be related for both energy services.

Electricity access, for the services it provides, is crucial to development. Notably, modern lighting provides numerous developmental benefits. Further, other services such as entertainment, education, and communication for instance are contingent on electricity access. Indicators related to appliances are included to capture elements related to the end-use side which are commonly left out of energy access metrics. Incorporating variables related to the ownership of appliances also brings in the notion of affordability. Indeed, the access to electricity, or modern fuels, is of limited use if the potential user does not have the financial means to pay for the fuel or to invest in the appliance to deliver the desired service. Therefore variables related to the possession of radio or TV and refrigerator are included. An indicator for telecommunication is also considered. Recent history has shown the crucial role of the use of phones and mobile phones in particular, which require the availability of energy, for socio-economic development.

Finally, whilst recognising the importance of mechanical power, it is not included it in the analysis because of the lack of reliable data.

Relative weights are assigned to the various dimensions and indicators, recognising the arbitrary nature of such a process. However, there are strong reasons to believe that the energy poverty variables considered in this energy poverty metric are not of equal importance. This notwithstanding, the fact that a weighting structure is value-laden must be dully acknowledged. The weights used in this analysis, as well as the selection of the indicators, are indicative and for the purpose of demonstrating the methodology. Those ought to be adapted to the specificities of the analyses.

3.3.4. Methodology

The methodology utilised is derived from the literature on multidimensional poverty measures, notably from the Oxford Poverty and Human Development Initiative (OPHI) (Alkire & Foster 2007 2009, 2011; Alkire & Santos 2010), which is inspired by Amartya Sen's contribution to the discussion of deprivations and capabilities. Sen (1999) argues for the need to focus on human poverty by considering the absence of opportunities and choices for living a basic human life.

The OPHI methodology is further developed to take into account some elements of uncertainty. Essentially, the MEPI captures the set of energy deprivations that may affect a person. It is composed of five dimensions representing basic energy services with six indicators (see Table 3-2). A person is identified as energy poor if the combination of the deprivations faced exceeds a pre-defined threshold. The MEPI is the product of a headcount ratio (share of people identified as energy poor) and the average intensity of deprivation of the energy poor.

Table 3-2: Dimensions and respective variables with cut-offs, including relative weights (in parenthesis)

Dimension	Indicator *(weight)*	Variable	Deprivation cut-off (energy poor if…)
Cooking	Modern Cooking fuel *(0.2)*	Type of cooking fuel	use any fuel beside electricity, LPG, kerosene, natural gas, or biogas
	Indoor pollution *(0.2)*	Food cooked on stove or open fire (no hood/chimney) if using any fuel beside electricity, LPG, natural gas or biogas	true
Lighting	Electricity access *(0.2)*	Has access to electricity	false
Services provided by means of household appliances	Household appliance ownership *(0.13)*	Has a fridge	false
Entertainment/education	Entertainment/education appliance ownership *(0.13)*	Has of radio OR television	false
Communication	Telecommunication means *(0.13)*	Has a phone land line OR a mobile phone	false

Formally, the MEPI measures energy poverty in d variables across a population of n individuals. $Y = [y_{ij}]$ represents the $n \times d$ matrix of achievements for i persons across j variables. $y_{ij} > 0$ therefore denotes the individual i achievement in the variable j. Thus, each row vector $y_i = (y_{i1}, y_{i2}, \ldots, y_{id})$ represents the individual i achievements in the different variables, and each column vector $y_j = (y_{1j}, y_{2j}, \ldots, y_{nj})$ gives the distribution of achievements in the variable j across individuals.

The methodology allows weighting the indicators unevenly if desired. A weighting vector w is composed of the elements w_j corresponding to the weight that is applied to the variable j. $\sum_{j=1}^{d} w_j = 1$ is defined. For the sensitivity analysis, and by means of capturing some of the uncertainty associated with assigning weights, probabilistic functions are applied to the respective weights. The functions are defined by using the deterministic weights shown in Table 3-2 as the mean of the respective normal probabilistic functions and set the standard deviation to 0.02.

z_j is defined as the deprivation cut-off in variable j, and then identify all individuals deprived in any variables. Let $g = [g_{ij}]$ be the deprivation matrix whose typical element g_{ij} is defined by $g_{ij} = w_j$ when $y_{ij} < z_j$ and $g_{ij} = 0$ when $y_{ij} \geq z_j$. In the case of the MEPI, the element of the achievement matrix being strictly non-numeric in nature, the cut-off is defined as a set of conditions to be met (see also Table 3-2). The entry ij of the matrix is equivalent to the variable weight w_j when a person i is deprived in variable j, and zero when the person is not deprived. Following this, a column vector c of deprivation counts is constructed, where the i^{th} entry $c_i = \sum_{j=1}^{d} g_{ij}$ represents the sum of weighted deprivations suffered by person i. It must be noted here that the technique whereby the weights are summed up, as opposed to a weighted score, is not novel in that it has been applied in a number of multi-criteria methodologies[34].

The persons multidimensionally energy poor are then identified by defining a cut-off $k > 0$ and applying it across the column vector. A person is considered as energy poor if her weighted deprivation count c_i exceed k. Therefore, $c_i(k)$ is set to zero when $c_i \leq k$ and equals c_i when $c_i > k$. Thus, $c(k)$ represents the censored vector of deprivation counts, and it is different to c in that it counts zero deprivation for those not identified as multidimensionally energy poor.

Finally, the headcount ratio H, which represents the proportion of people that are considered energy poor[35], is computed. With q as the number of energy poor people (where $c_i > k$) and n the total, $H = q / n$ represents the incidence of multidimensional energy poverty. The average of the censored weighted deprivation counts $c_i(k)$ represents the intensity of multidimensional energy poverty A. More formally, $A = \sum_{i=1}^{n} c_i(k) / q$. The MEPI captures information on both the incidence and the intensity of energy poverty, and is defined as $MEPI = H * A$.

For the uncertainty analysis, a Monte Carlo method is used to compute the MEPI recurrently ($n=1000$) based on the normally distributed random weights. The results are in turn non-deterministic and are in the form of probability density functions due to the stochastic weights. Based on this, the respective uncertainty bands arbitrarily defined as the range between the 5^{th} and 95^{th} percentile are derived.

The MEPI methodology provides a number of advantages. Notably, it focuses on the energy services and is based on data related to energy deprivations, as opposed to deriving information indirectly through variables that are presumed to be correlated (e.g. energy or electricity consumption). Additionally, it captures both the incidence (number of energy poor people) as well as the intensity (how energy poor they are). Related to this, the OPHI methodology, applied here to energy poverty,

34 E.g. ELECTRE (ELimination Et Choix Traduisant la REalité).

35 For the sake of the simplicity of the argument, we refer in the first section of the description of the methodology to the individual as a unit. The data used stem from household surveys, the first steps of the calculation are made at household level, under the assumption that energy poverty can be characterized at such level. When computing the headcount and the average censored weighted deprivation, we include the number of persons per household (data available from the surveys), as well as the sampling weight to ensure representativeness.

respects the condition of dimensional (or variable) monotonicity. That is, both if an additional person becomes poor and if a person already considered as multidimensionally poor becomes poor in additional variable(s), it is reflected by an increase in the aggregated value. Another virtue of the methodology is its decomposability. Because the data used as input are at micro-level (households or individuals), the tool allows for a wide range of analyses focusing on sub-groups (e.g. wealth classes).

3.4. Results

The MEPI is calculated for all the African countries for which appropriate data are available[36], setting the multidimensional energy poverty cut-off *k* to 0.3. It implies that a person is considered as energy poor if, for instance, she has no access to clean cooking or does not benefit from energy services supplied by electricity.

Figure 3-1 shows the results for the MEPI in Africa. The countries are classified according to the degree of energy poverty, ranging from acute energy poverty (MEPI>0.9; e.g. Ethiopia) to moderate energy poverty (MEPI<0.6; Angola, Egypt, Morocco, Namibia, Senegal). The details on the results for the headcount ratio, intensity of poverty and MEPI are available in Annex 3-A. As complementary information, individual indicators, such as the electrification rate and the rate of use of modern[37] cooking fuels, are also reported upon in the same annex.

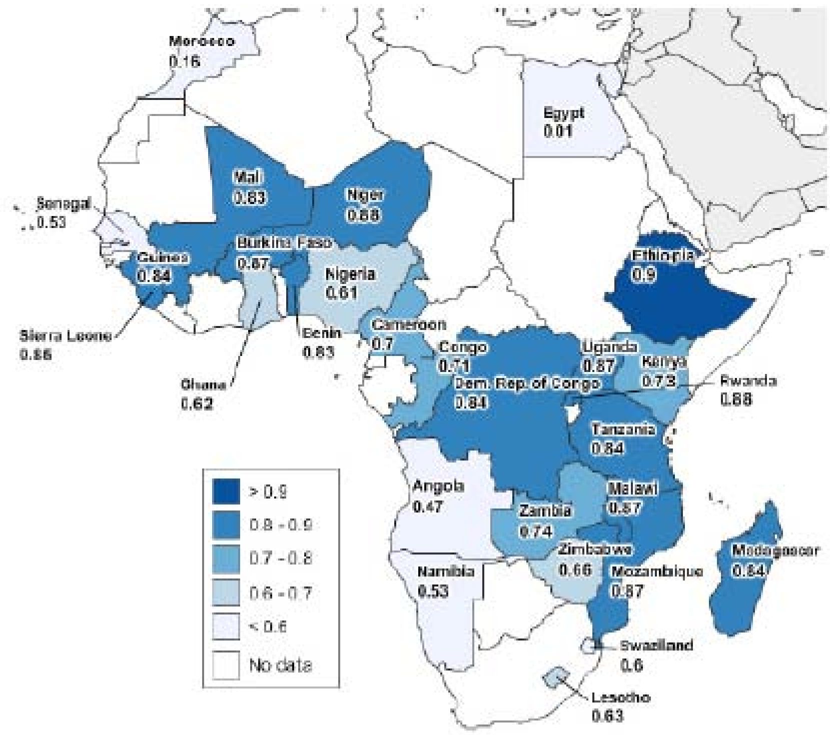


Figure 3-1: MEPI for selected African countries

Visual created with van Cappelle, n.d.

National statistics often mask significant sub-national disparities. To test this, the MEPI is computed at the district level in Kenya, as an illustration. Figure 3-2 shows a stark contrast with regard to the level of energy poverty between the capital, where the MEPI is similar to that of the country of Morocco, and the Western and North Eastern districts which suffer from severe energy poverty.

[36] That is, data for the indicators of the MEPI are available in the DHS dataset from survey phase IV and/or V.

[37] i.e. non solid.

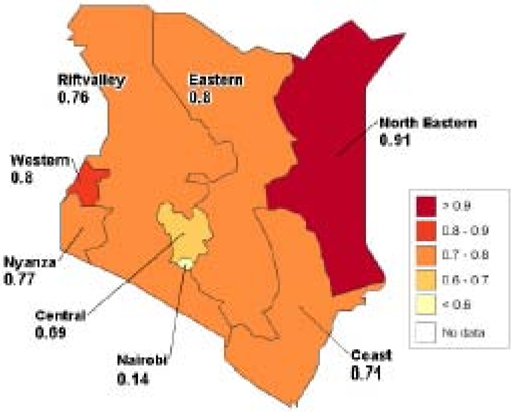


Figure 3-2: MEPI at sub-national level (Kenya)

The next step is the decomposition of the energy poverty metric based on wealth categories. Showcasing two examples, Figure 3-3 indicates that the energy poverty stratification varies notably between countries. While the MEPI in the two most economically deprived and well-off quintiles in Ghana and Zambia is comparable, it is notably different for the middle classes. In Zambia, there is a steep decline in energy poverty when moving from the richer to the richest quintile, whereas the reduction in energy poverty appears to be more evenly distributed in the case of Ghana.

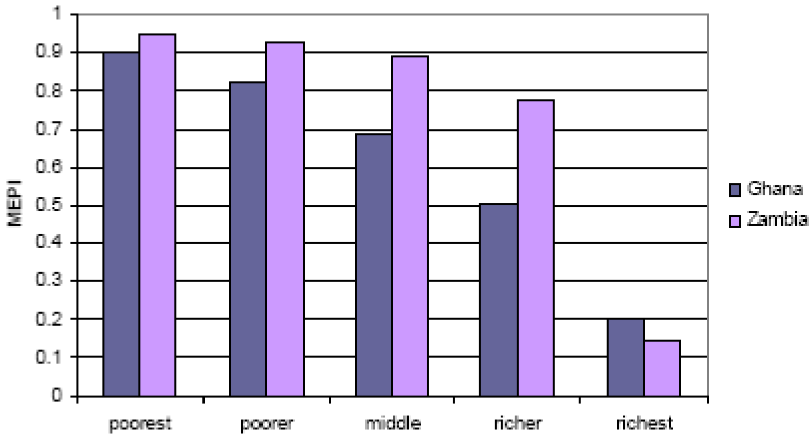


Figure 3-3: MEPI by wealth index quintile in Ghana and Zambia

In Figure 3-4, the headcount ratio, i.e. the ratio of people considered as energy poor, is plotted against the intensity of poverty which indicates how poor the energy poor are. It is useful to consider the outliers on the graph. It indicates that for the countries below an imaginary trend line, the intensity of energy poverty is significantly higher compared to the headcount ratio of energy poor. The opposite holds for those countries above the line. In other words, although the MEPI value of Ghana and Nigeria is comparable, the ratio of people experiencing energy poverty is higher in Ghana. In contrast, the intensity of energy poverty is greater in Nigeria. Similarly, the intensity of energy poverty is almost identical between Malawi and Zambia. Nonetheless, there are more energy poor, in relative terms, in the former than in the latter.

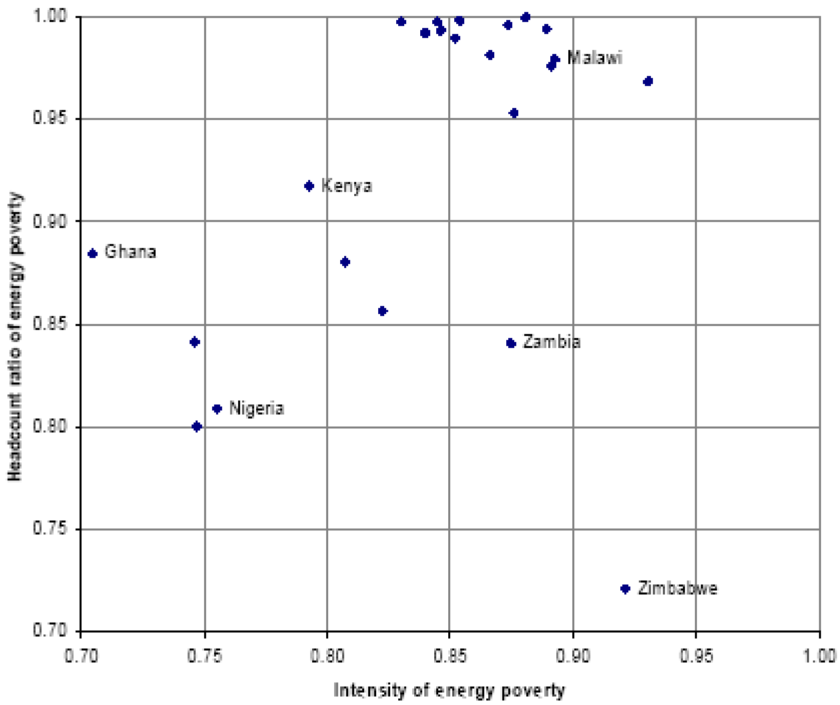


Figure 3-4: Headcount ratio vs. intensity of energy poverty for sub-Saharan countries

For a few countries, data are available from DHS surveys of phases IV and V[38]. Based on this, it is possible to explore, to a small degree, the evolution of the MEPI over time. Figure 3-5 shows the results of the MEPI computed based on both survey datasets. Although the finding is not robust enough to allow generalization, the graph seems to indicate that progress in reducing energy poverty happens more rapidly as energy poverty declines[39]. For instance, the difference in the MEPI between the two data sets is greater for Ghana and Namibia than for the other countries. Another observation is that one can note a reduction in energy poverty in all countries but Zimbabwe.

[38] DHS surveys phases IV and V span 1997-2003 and 2003–present, respectively.

[39] To test this, we carry out a correlation analysis between the MEPI score of the phase IV and the difference in the MEPI score between both phases shows to find a negative correlation, as expected. The tendency (not statistically relevant at 95%) is therefore for the difference in the MEPI over time to be greater when the energy poverty level is lower initially; ($b = -.48$, $p < 0.51$, $R^2 = 0.04$).

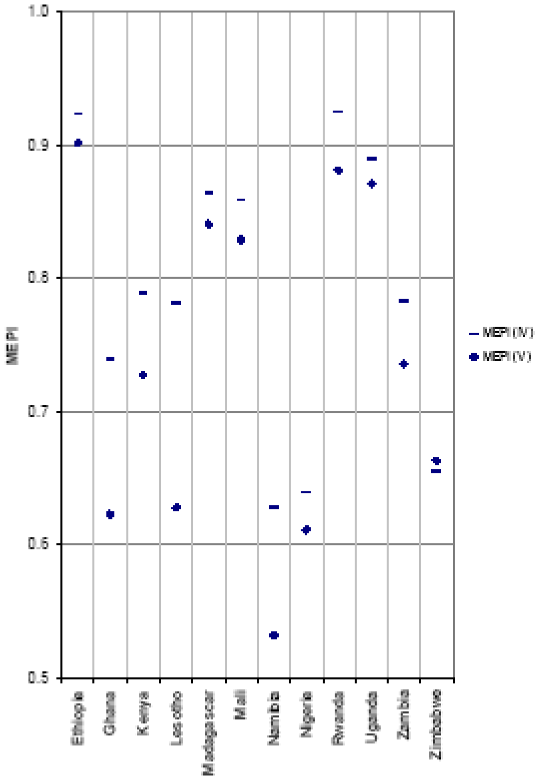


Figure 3-5: Evolution over time of the MEPI (based on comparison between data from DHS surveys of phases

3.4.1. Comparison with other indices

Next, the new metric we created is compared with the landmark Energy Development Index (EDI) from the IEA (see e.g. IEA 2010). It must be underlined here that the EDI and the MEPI, while both designed to provide information with regard to access to modern energy services, focus on different aspects of energy for development. The EDI is a measure of energy system transition towards modern fuels whereas the MEPI evaluates energy poverty. With this in mind, Figure 3-6 shows the comparison between the MEPI and EDI for all African countries for which data are available for both metrics. As expected, the two indices are negatively correlated. That is, the EDI shows a lower level of energy system development for those countries for which the MEPI has identified acute energy poverty. The MEPI and the EDI are complementary measures which characterize different aspects of the energy – development nexus.

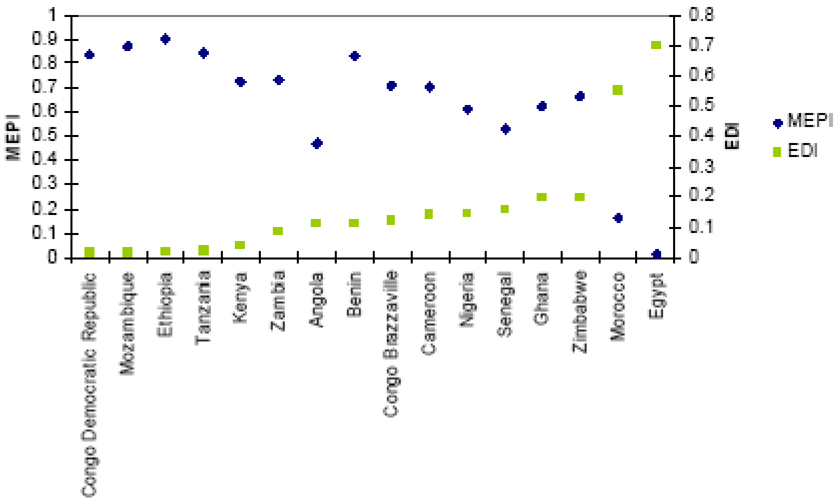


Figure 3-6: Comparison between MEPI and EDI for selected African countries

Data source for EDI: IEA (2010).

Finally, the outcomes of the MEPI with the HDI[40], arguably the reference index for human development, are also compared to gain insight on the hypothesis of the strong link between energy and development. Figure 3-7 shows a negative correlation between the two indices ($b = -.31$, $p < 0.000$, $R^2 = 0.43$).

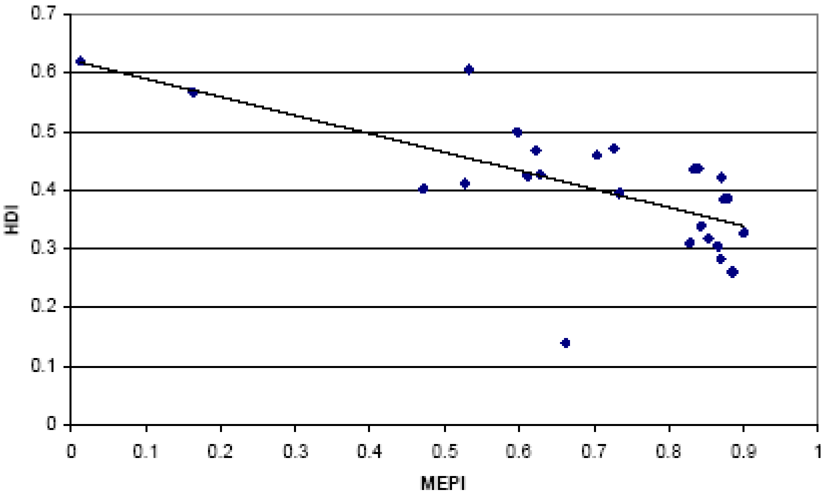


Figure 3-7: Comparison between MEPI and HDI for selected African countries

Data source for HDI: UNDP (2010).

3.5. Discussion

There needs to be some degree of pragmatism in the development of an index that is easily computable, flexible enough to be used in various contexts, and that acknowledges the issues related to the lack of availability of reliable, comprehensive datasets. It must be reiterated that composite indices, by their very nature, are incapable of reflecting the full extent of the complexity of the issue they measure. Regardless of the specifics of the model, a composite index will always involve some form of reduction of the variety of information included in the various indicators individually. Also, the value of analysing the indicators independently is not disputed; the MEPI makes a case for the additional value of constructing an aggregated measure.

The issue of weights has generated much debate in the literature. Every aggregated multidimensional measure places some weights on the various factors, either explicitly or implicitly. In this analysis, the weights have been defined based on 'expert opinion' for the purpose of demonstrating the methodology. The arbitrary nature of those is dully recognised, as well as the fact that the weighting structure might have to be adjusted depending on the objective of the analysis and context.

The quality of a composite index, apart from the issues related to the aggregation model, is intrinsically linked to the quality of its components and thus the quality and reliability of the underlying variables. This represents a critical issue in the case of energy poverty, since it systemically lacks an information base that is of quality, reliability, and comprehensive, despite current and most welcome efforts to improve it. The data used for this analysis represent imperfect proxies drawn from surveys, which have their own limitations, not specifically developed for energy purposes.

The following section summarises the outcome of a series of sensitivity analyses intended to test the robustness of the methodology and the results.

3.5.1. Sensitivity analysis

Beside the data issue, there is also uncertainty inherent to the methodology and assumptions. Indeed, the choice of the indicators, constrained by the availability of data, as well as the structure of the

[40] Edition 2010.

aggregating model influence the outcome of the analysis. With this in mind, a series of tests is presented by modifying some of the key parameters.

- The cut-off of multidimensional poverty, k, is changed to evaluate the impact on the MEPI. To this purpose, the countries are classified in deciles based on the MEPI and the change in classification when the cut-off is altered (between 0.2 to 0.4) is considered to assess the robustness of the analysis (see results in Annex 3-B). The change in the energy poverty cut-off does not lead to significant changes in the country classification. In fact, only two countries (Lesotho and Swaziland) change decile in this analysis. Annex 3-C shows the change in the MEPI in absolute terms.
- The stability of the country rankings to changes in the multidimensional poverty cut-off is tested by applying two different methodologies, namely the Spearman's and Kendall's rank correlation coefficient[41]. The results (see Annex 3-D) show a very high correlation between the rankings, ranging from 0.9956 to 1 for the Spearman test and from 0.9735 to 1 for that of Kendall, implying that the change in the cut-off only marginally affects the results.
- In addition to this, and as described in the methodology section, the algorithm of the MEPI is computed with the weights as logistic functions as a means of capturing some of the uncertainty associated with determining those. The output is a probability density function. Figure 3-8 summarises the results by showing the MEPI score together with the respective uncertainty band that is arbitrarily defined as the range between the 5th and 95th percentile of the probability density function. The graph provides a sense of the effect of slightly varying the weighting structure. It is important to note that the generated pseudo-confidence intervals are to be interpreted with care. They are useful to account for some of the uncertainty about the weights, and provide indications related to the robustness of cross-country comparisons[42].

[41] The Spearman's rank correlation coefficient is based on the changes in country ranks between a pair of rankings, whereas the Kendall's coefficient is calculated by comparing each pair of countries in a pair of rankings.

[42] For instance, they allow for probing statements like: 'With the most favourable weights, country A does not fare better than country B with the least favourable weights'.

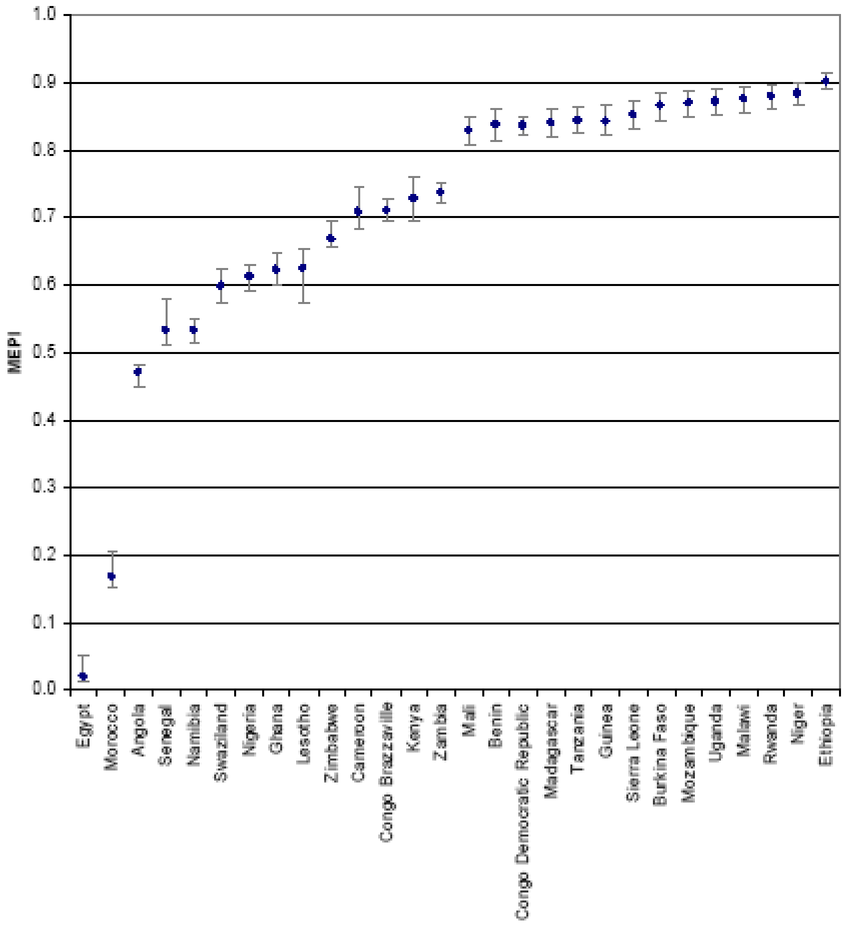


Figure 3-8: MEPI including the pseudoconfidence interval due to the uncertainty in the weighting of the indicators

The effect is different amongst the countries. The outcome of the stochastic computation of the MEPI is presented graphically for selected countries in Annex 3-E. The graphs show that, in some cases, the dispersion is relatively small (e.g. Zambia: $\sigma = 0.0087$) whereas it can be notably greater for others (e.g. Kenya: $\sigma = 0.0197$).

Also, the probability density functions resulting from the stochastic computing of the MEPI are close to being normally distributed in most cases. As illustrative examples, the skewness is 0.031 and -0.028 for Zambia and Kenya, respectively. However, the skewness is more pronounced for a few countries, such as Angola (-1.240). See also Annex 3-E for a graphical representation. The non-normal distribution of the results calls for caution in applying the methodology with deterministic parameters. Indeed, in those cases, the score is relatively sensitive to the choice of weights and multidimensional cut-off.

3.5.2. Further work

A new tool to measure energy poverty at various levels has been outlined and tested. There are a number of possible refinements in terms of both the methodology itself and its application and further testing.

The indicators picked for this analysis, as well as the various parameters chosen, are for the purpose of illustrating the application of the methodology. The results, as insightful as they might be, must be interpreted bearing in mind that they depend on the underlying model. Further work could include applying the methodology in various contexts. For instance, there is scope for refining the methodology to assess very high levels of energy poverty in more detail. The analysis of those cases would most likely benefit from a specific set of indicators and weights, as well as possibly another source of data.

An intermediate step would be to decompose the current analysis and assess the composition of energy poverty in detail to gather insights from the differences between countries. Indeed, valuable policy insights could be derived from a better understanding of what constitutes energy poverty in different contexts. For instance, in Benin, some households benefit from electricity but access to modern cooking is predominantly low. In contrast and with a similar energy poverty headcount ratio, Ethiopian households are better off in comparison with regard to cooking, but the electrification rate is notably lower.

Another area of further work is the extension of the application of the methodology to other regions and countries, including those for which the datasets are patchy. Beside this, a periodical updating of the analysis would be most useful. It might be appropriate, though, to consider changes in the set of indicators, weights and cut-offs, as data improve.

3.6. Conclusion

Providing a rigorous analytical basis for policy-making by developing and applying a robust set of metrics for measuring energy poverty is central to the implementation of any global, regional or national target. Designing the measurement toolbox and implementing a reporting system can help move energy access to the heart of the development agenda. The methodology outlined and tested in this paper contributes to efforts geared towards providing evidence-based information to inform the design and implementation of measures and policies to address the issue of energy poverty.

A tool to evaluate energy poverty at various levels – the Multidimensional Energy Poverty Index (MEPI) has been developed and its application demonstrated. The MEPI, while constrained by the data paucity characterising this field of work, is innovative on a number of grounds. The methodology is based on the concept of multidimensional poverty and is inspired by the relevant literature. The index is composed of two components: a measure of the incidence of energy poverty, and a quantification of its intensity. The methodology focuses on the deprivation in terms of energy, and places energy services at the core of the analysis. Also, as the quantification is based on detailed and extensive micro-data stemming from household surveys, a great deal of decomposition analysis is possible which provides a wealth of policy relevant information. Nevertheless, the MEPI will only form one instrument in monitoring progress and designing and implementing good policy in the area of energy poverty.

Annex 3-A: Detailed results for African countries: Headcount ratio and intensity of energy poverty, and the composite MEPI, as well as individual indicators, alongside other related indices

Country (year of most recent DHS survey)	Headcount ratio	Intensity of energy poverty	MEPI	Electrification [%]	Modern cooking fuel [%]	EDI	HDI
Angola (2006-07)	0.59	0.79	0.47	41.6	52.5	0.111	0.403
Benin (2006)	0.99	0.84	0.83	22.2	0.7	0.111	0.435
Burkina Faso (2003)	0.98	0.87	0.87	10.4	2.0		0.305
Cameroon (2004)	0.86	0.82	0.70	46.2	16.0	0.138	0.46
Congo Brazzaville (2009)	0.88	0.81	0.71	34.7	15.0	0.122	
Congo Democratic Republic (2007)	0.95	0.88	0.84	17.6	4.6	0.012	
Egypt (2008)	0.03	0.48	0.01	99.4	99.5		0.62
Ethiopia (2005)	0.97	0.93	0.90	12.2	3.4	0.019	0.328
Ghana (2008)	0.88	0.70	0.62	56.1	11.7	0.195	0.467
Guinea (2005)	1.00	0.85	0.84	20.9	0.2		0.34
Kenya (2008-09)	0.92	0.79	0.73	18.2	9.7	0.038	0.47
Lesotho (2009)	0.84	0.75	0.63	15.7	33.9		0.427
Liberia (2007)			([43])	3.3			0.3
Madagascar (2008-09)	0.99	0.85	0.84	16.5	0.6		0.435
Malawi (2004)	0.98	0.89	0.87	7.5	2.0		0.385
Mali (2006)	1.00	0.83	0.83	17.5	0.3		0.309
Morocco (2003-04)	0.29	0.57	0.16	76.7	89.9		0.567
Mozambique (2003)	0.98	0.89	0.87	11.0	2.8	0.015	0.284
Namibia (2006-07)	0.67	0.79	0.53	39.3	35.4		0.606
Niger (2006)	0.99	0.89	0.88	10.5	0.6		0.261
Nigeria (2008)	0.81	0.75	0.61	47.9	20.9	0.144	0.423
Rwanda (2007-08)	1.00	0.88	0.88	6.7	0.0		0.385
Senegal (2005)	0.66	0.80	0.53	46.5	38.9	0.157	0.411
Sierra Leone (2008)	1.00	0.85	0.85	11.1	0.1		0.317
Swaziland (2006-07)	0.80	0.75	0.60	29.9	24.0		0.498
Tanzania (2007-08)	0.99	0.85	0.84	10.9	1.5	0.025	
Uganda (2006)	1.00	0.87	0.87	7.7	0.5		0.422
Zambia (2007)	0.84	0.87	0.74	21.0	16.0	0.083	0.395
Zimbabwe (2005-06)	0.72	0.92	0.66	34.0	29.9	0.197	0.14

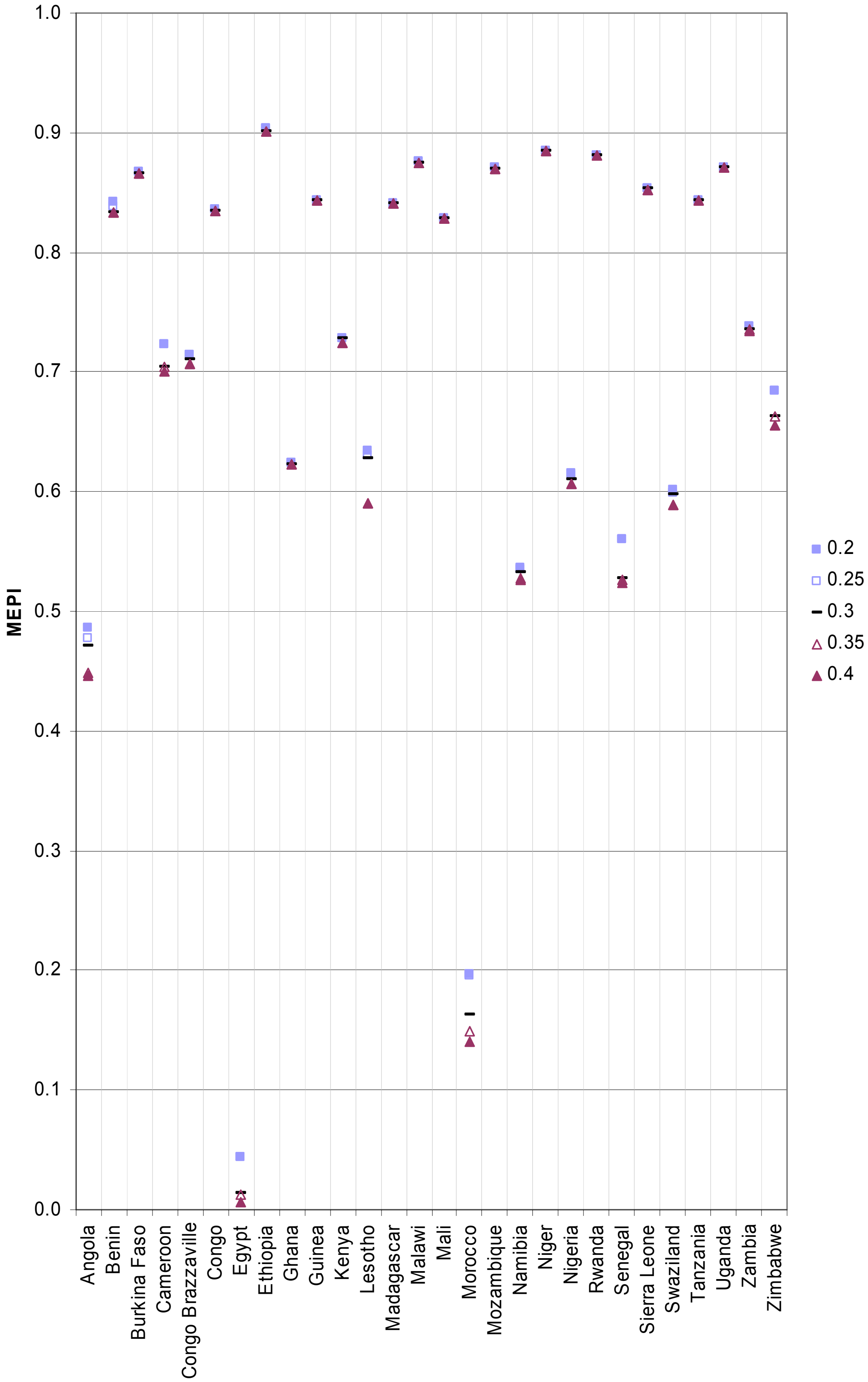
Sources: own calculation from MEASURE DHS (2010); EDI: IEA (2010); HDI: UNDP (2010)

[43] Not available; missing data.

Annex 3-B: Effects of multidimensional energy deprivation cut-off change on distribution of countries in deciles

MEPI deciles	0.2	0.25	0.3	0.35	0.4
1 (highest)	Ethiopia	Ethiopia	Ethiopia	Ethiopia	Ethiopia
2	Benin Burkina Faso Congo Democratic Republic Guinea Madagascar Malawi Mali Mozambique Niger Rwanda Sierra Leone Tanzania Uganda	Benin Burkina Faso Congo Democratic Republic Guinea Madagascar Malawi Mali Mozambique Niger Rwanda Sierra Leone Tanzania Uganda	Benin Burkina Faso Congo Democratic Republic Guinea Madagascar Malawi Mali Mozambique Niger Rwanda Sierra Leone Tanzania Uganda	Benin Burkina Faso Congo Democratic Republic Guinea Madagascar Malawi Mali Mozambique Niger Rwanda Sierra Leone Tanzania Uganda	Benin Burkina Faso Congo Democratic Republic Guinea Madagascar Malawi Mali Mozambique Niger Rwanda Sierra Leone Tanzania Uganda
3	Cameroon Congo Brazzaville Kenya Zambia	Cameroon Congo Brazzaville Kenya Zambia	Cameroon Congo Brazzaville Kenya Zambia	Cameroon Congo Brazzaville Kenya Zambia	Cameroon Congo Brazzaville Kenya Zambia
4	Ghana Lesotho Nigeria Zimbabwe **Swaziland**	Ghana Lesotho Nigeria Zimbabwe	Ghana Lesotho Nigeria Zimbabwe	Ghana Nigeria Zimbabwe	Ghana Nigeria Zimbabwe
5	Namibia Senegal	Namibia Senegal Swaziland	Namibia Senegal Swaziland	**Lesotho** Namibia Senegal Swaziland	**Lesotho** Namibia Senegal Swaziland
6	Angola	Angola	Angola	Angola	Angola
7					
8					
9	Morocco	Morocco	Morocco	Morocco	Morocco
10 (lowest)	Egypt	Egypt	Egypt	Egypt	Egypt

Annex 3-C: Effects of multidimensional energy deprivation cut-off change on the MEPI



Annex 3-D: Correlation in the countries ranking when the multidimensional energy deprivation cut-off is changed

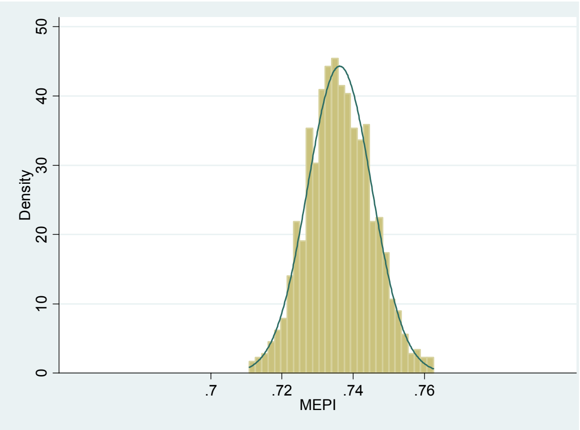
Spearman	0.2	0.25	0.3	0.35	0.4
0.2	1				
0.25	0.9995*	1			
0.3	0.9973*	0.9984*	1		
0.35	0.9956*	0.9967*	0.9984*	1	
0.4	0.9956*	0.9967*	0.9984*	1.0000*	1

Note: n=28; *: statistically significant at 99%

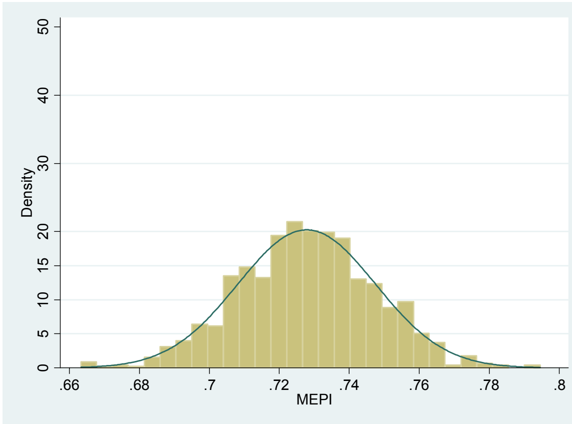
Kendall	0.2	0.25	0.3	0.35	0.4
0.2	1				
0.25	0.9947*	1			
0.3	0.9788*	0.9841*	1		
0.35	0.9783*	0.9735*	0.9894*	1	
0.4	0.9783*	0.9735*	0.9894*	1.0000*	1

Note: n=28; *: statistically significant at 99%

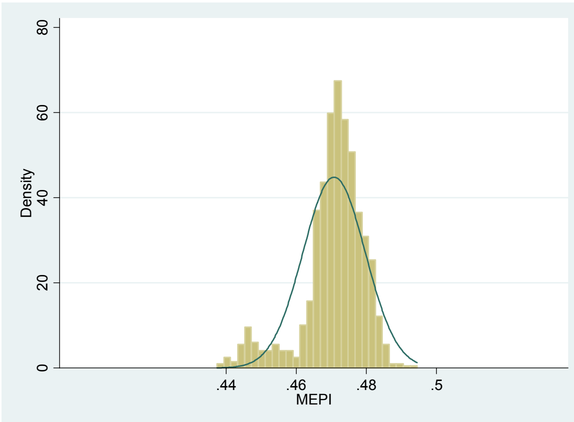
Annex 3-E: Selected illustrative detailed MEPI results as probability density functions with fitted normally distributed function



Zambia



Kenya



Angola

4. Energy Access Scenarios to 2030 for the Power Sector in Sub-Saharan Africa

4.1. Introduction

The provision of reliable, secure, and affordable energy services are central to addressing many of today's global development challenges, including poverty, inequality, climate change, food security, health and education. The link between energy and the Millennium Development Goals (MDGs) has been discussed extensively in the literature (e.g., Modi et al. 2005; AGECC 2010) and energy poverty is acknowledged as undermining achievement of the MDGs. The obstacles to widespread energy access, and specifically electricity access, are largely well known (i.e., financing, planning, governance, and human and institutional capabilities), yet not trivial to overcome. While there are no fundamental technical obstacles preventing universal energy access, there is, however, a lack of effective institutions, good business models, transparent governance, and appropriate legal and regulatory frameworks, etc.

Current actions to eliminate energy poverty are falling short both in terms of scale and pace. In fact, if current trends continue, more people in Africa will be without access to modern energy services in 2030 than today (IEA, UNDP & UNIDO 2010). Changing this requires global political commitment that goes beyond abstract political statements and sets out actions and associated benchmarks (Bazilian, Nussbaumer, Cabraal, et al. 2010). To that end, a goal of achieving sustainable energy for all, with a 2030 target of providing universal access to modern energy services, was put forth to the international community in 2010 by the United Nations Secretary-General's Advisory Group on Energy and Climate Change (AGECC 2010). Supporting this goal, the United Nations General Assembly declared 2012 as the *International Year for Sustainable Energy for All*[44]. Thus, the time is ripe for scaling-up efforts.

To help inform debate, investment, and more detailed analysis, we focus on the economy-wide electricity sector, and review the literature and present several simple and transparent scenarios for the sub-Saharan African (SSA) power sector to 2030. We mainly focus on those countries with very low rates of access to electricity services and so generally exclude the Republic of South Africa (RSA) from the analysis. The scenarios are simple because we generally employ simplified power system planning and forecasting methods, and focus primarily on one metric, namely, installed generation capacity. (As a result, issues of cost are generally outside the scope of this paper.) They are transparent because we clearly identify all inputs and parameters, as well as present ranges for our assumptions. We focus on generation capacity as a useful metric to communicate the issue, as it is more easily understandable to a non-specialist audience than, say, electricity demand. (In other words, it is easier to discuss electricity supply issues in terms of power plants (i.e., MW) than electrical power (i.e., TWh).) This work is aimed at helping at improving understanding about the scale of reaching universal access to electricity services in SSA and the resultant decision-making processes. Hence, it serves to refine input assumptions, parameters, and the nature of outputs from future, more detailed analysis, while informing decision-making today.

Section 2 briefly reviews the related literature and discusses various approaches for energy planning and demand projections. It also touches upon the associated issues of capacity building and data paucity. In Section 3, a concise historical overview of power systems in Africa is presented. Related published or on-going modeling efforts are described in Section 4. In Section 5, we present some simple energy access scenarios. Finally, Section 6 presents conclusions.

4.2. Energy Planning

Comprehensive energy systems planning aims at ensuring that energy-related policy and investment decisions consider all possible energy supply and demand side options, and are consistent with broader national goals (e.g., sustainable development). A necessary prerequisite, however, is the existence of

[44] For more information: http://www.sustainableenergyforall.org.

national energy planning capability (capacity). Energy planning capacity increases a country's ability to anticipate and respond to the rapid changes occurring, and new issues and opportunities arising. The value of this asset increases over time, as experts gain experience in applying their skills, build the local knowledge base and forge relationships with stakeholders from diverse sectors. Inadequate national planning capability and consequent poor policy and investment decisions in the past have led to disparate level of access to modern energy services. Energy planning is also a matter that extends beyond national borders, especially for smaller countries with underdeveloped energy resource potentials (e.g., hydropower) or where sharing infrastructure with neighbours would provide economies-of-scale.

There is a large ongoing discussion around market reform and liberalization in SSA power systems. (As an illustration of this, Eberhard et al. (2011) dedicate an entire chapter on reforming State-owned enterprises.) Over the last 20 years many developing countries have adopted far-reaching policies that encourage liberalization and privatization, often at the behest of major international funders and development organizations. While these policies have often improved the 'health' of individual national utilities, with very few exceptions they have not led to dramatic increases in energy access, for the simple reason that meeting the electricity needs of the poorest is not very profitable for utilities. This debate coincided with the same dialogue that occurred in the OECD over the last two decades; in these industrialised countries it too has had very mixed results. The clear benefits of liberalizing these mostly fragile markets are unclear, where it has been ideologically pushed on to these countries, it is often to their detriment, despite good intentions.

Like many facets of public policy, energy policy has been informed by recourse to analytical models. However, the outputs, temporal and spatial scope, sophistication, language, assumptions, system boundaries, and theoretical frameworks of these analytical tools vary dramatically. Thus, the results of these analyses require some considerable level of filtration and translation in order to appropriately inform design and implementation of government policy. *Apropos* of this, Munson (2004) notes that there is a, "disconnect between the questions policy makers want answered and the results provided by modelling exercises". Power system analyses can be considered a sub-set of energy system modelling.

Power system analyses, management and planning are used over various timeframes – from sub-second (load balancing) to several decades (capacity expansion). The planning methodologies employed and the aims of the analytical work vary accordingly. We focus on the long-term, i.e. over a 5-20 year time horizon, the foundation of which is normally a set of electricity (or energy) demand projections. Electricity capacity expansion planning generally tends to be based on some type of least-cost optimisation given various constraints that mirror existing physical infrastructure conditions, access to finance, public policy regarding environment protection or energy security considerations. Many modern mathematical techniques ranging from fuzzy logic, to evolutionary programming, to mixed integer linear programming and multi-objective optimisation are in general use in government planning offices and utilities worldwide. A trend towards accommodating various aspects of uncertainty and liberalized markets is apparent in recent research in this subject. However, for most power systems in sub-Saharan Africa, a high level of methodological sophistication may not be required to get underway with generation and infrastructure planning.

A clear issue that emerges in energy planning relates to data paucity and quality (Bazilian, Nussbaumer, Cabraal, et al. 2010). Energy modeling, which lies at the heart of most planning processes, tends to be very data-intensive, which creates obstacles for many countries (Howells et al. 2010). A reliable and comprehensive information base is required to set targets and monitor outcomes, to design strategies and policies, to make evidence-based decisions, and to enable consumers to make informed choices. Moreover, poor and inconsistent national statistics limit cross-country analysis and undermine efforts to implement global or regional programmes. Still, a lack of data, should not be used as a justification for delaying building national energy planning capability and developing energy plans. Missing data can be derived from first principles or estimates, and used as placeholders until better data become available. Interestingly, the availability of good quality public domain data has, in some cases, also been hampered by market liberalization in the energy sector over the past 20 years, with the consequence that some of the data most useful to national energy planners is now proprietary

4.2.1. Energy demand projections

Energy demand projections represent a crucial component in most planning endeavours. As mentioned, different tools and methods (see Table 4-1) of various degree of complexity are used to estimate future demand.

Table 4-1: Selected methods utilised for energy demand projections

Type	Description
Trend method	Non-causal model, i.e. it does not explicitly explain how the projected variable is determined, which is purely a function of time (e.g., x% increase per year).
End-use method (or engineering based method)	Approach based on energy usage patterns of appliances and systems.
Agent-based models	Class of computational models for simulating the actions and interactions of autonomous agents (both individual and collective entities) with a view to assessing their effects on the system as a whole. The models simulate the simultaneous operations and interactions of multiple agents, in an attempt to re-create and predict the appearance of complex phenomena.
Time series method	Projections solely based on historical patterns in the data.
Econometric method	Standard statistical tools are employed to produce a mathematical representation of the energy demand as a function of a series of variables (e.g., population, GDP). The functions derived can then be used to project the demand into the future, assuming that the causal relationships remain unchanged over time. Alternatively causal relationships are guided by normative of policy objectives.
Neural network techniques	Techniques which are able to capture and represent complex input/output relationships, both linear and non-linear. The advantage is the ability to learn these relationships directly from the data being modeled. Usually used for short-term load forecasting.

Note: adapted from McDowall and Eames (2006)

The various approaches have their respective strengths and weaknesses. The choice of the appropriate method is contingent on a number of factors, notably on the nature and the availability of underlying data as well as on the purpose of the analysis and timeframe. For many of the long-term planning exercises conducted in SSA, demand projections are based on some econometric relationship to income (GDP) and population growth projections, along with an elasticity relationship. In addition, some have explicit terms for household connections, and large point.

These well-understood techniques, based on aggregates such as GDP and exogenous inputs like future annual grid connections of households, are not ideally suited for situations where much of the population lacks access to electricity services. In these cases, a different type of approach is needed, for example solving for a future goal and back-casting, rather than forecasting based on historical trends. Ensuring that the type of analysis is appropriate for the policy and investment questions is essential. It has been argued that in a severely supply-constrained electricity system, demand projections are less important than capacity expansion planning and associated finance. In other words, in typical developing country situations additional supply would create its own demand.

4.3. Historical Energy Trends

Sub-Saharan Africa suffers acutely from a lack of access to electricity and poor quality of supply, in terms of cost and reliability, where it does exist. There are approximately 580 million people on the continent without access (IEA, UNDP & UNIDO 2010) – the bulk of them living in rural areas. Overall the electrification rate in SSA is around 30% (60% urban; 14% rural) (IEA, UNDP & UNIDO 2010). Full analysis of the energy landscape for Africa is available from several sources (e.g., Foster and Briceno-Garmendia 2010; Eberhard et al. 2011). The recent power system academic literature on the topic of Africa is dominated by discussions around solar power in North Africa. Also, much of the literature on the power sector in SSA is not surprisingly focused on the Republic of South Africa (RSA). However, there has been a steady group of dedicated researchers focusing on SSA or on particular SSA countries. Still, there is a relatively small existing literature on scenarios for the power sector in sub-Saharan Africa.

The total average per capita annual consumption in SSA (excluding RSA) is around 155 kWh (based on 2008 EIA data). These figures are minute compared to South Africa (4,770 kWh/per capita) or Organisation for Economic Co-operation and Development (OECD) countries (e.g., Chile: 3,327 kWh/per capita; Germany: 7,148 kWh/per capita; USA: 13,647 kWh/per capita).

Figure 4-1 shows the total electricity generation capacity installed per million persons (MW/mln) in various regions. It is recognised that this is a relatively rough metric as it does not take into account a number of crucial parameters, including: transmission and distribution (T&D) losses, load patterns, locational constraints, intermittency, temporal reserve, availability, operating efficiency, and outage rates. Compared to other world regions, the ratio of electricity generation capacity per million inhabitants is low in Africa, particularly in sub-Saharan Africa. As illustrative examples of the installed capacity per million of population: Chad and Rwanda: 3 MW/mln; Ethiopia: 10 MW/mln; Cameroon: 54 MW/mln; Ghana: 72 MW/mln; Cape Verde: 150 MW/mln; Namibia: 192 MW/mln; South Africa: 854 MW/mln. The figure for Sub-Saharan Africa (excluding RSA) was roughly 129 MW/mln in 2008 only considering people with electricity access; if the entire population is included, the total is about 40 MW/mln.

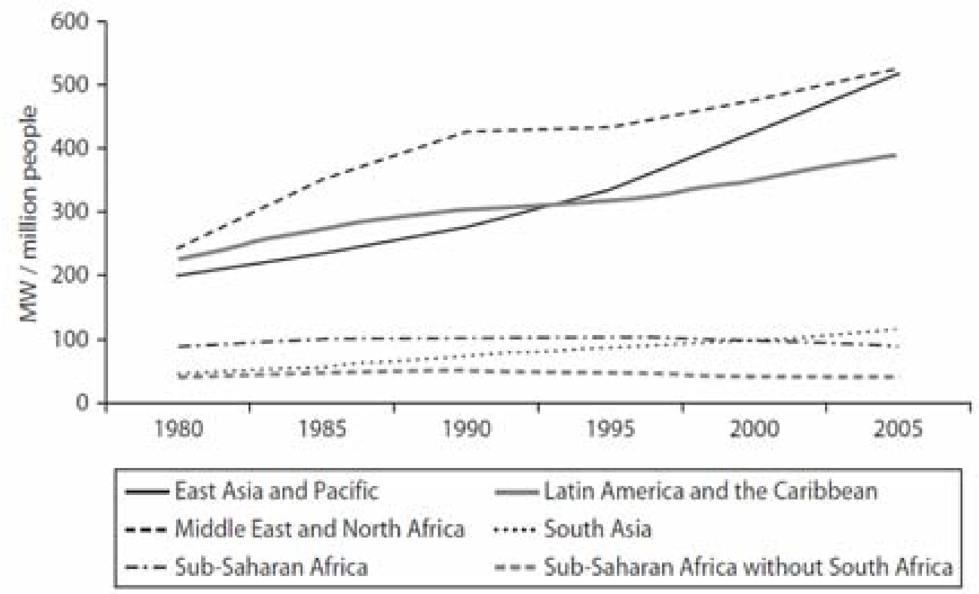


Figure 4-1: MWs installed per one million people by region

Source: Eberhard et al. 2011

In terms of electrification of the underserved, history provides compelling evidence that significant increases in the percentages of households with access to electricity can be achieved over relatively short periods of time. For instance, electrification rose sharply in a number of countries, such as the USA and UK early in the 20th century, and in China, Brazil, and Thailand more recently (see Figure 4-2). In the case of Thailand, the percentage of the population with access to electricity went from about 25% to almost 100% in a decade. Still, most countries take at least three decades to make this transition – and most quite a bit longer. In all these countries, electrification, particularly of rural areas, was accorded a high national priority because of economic development or equity objectives.

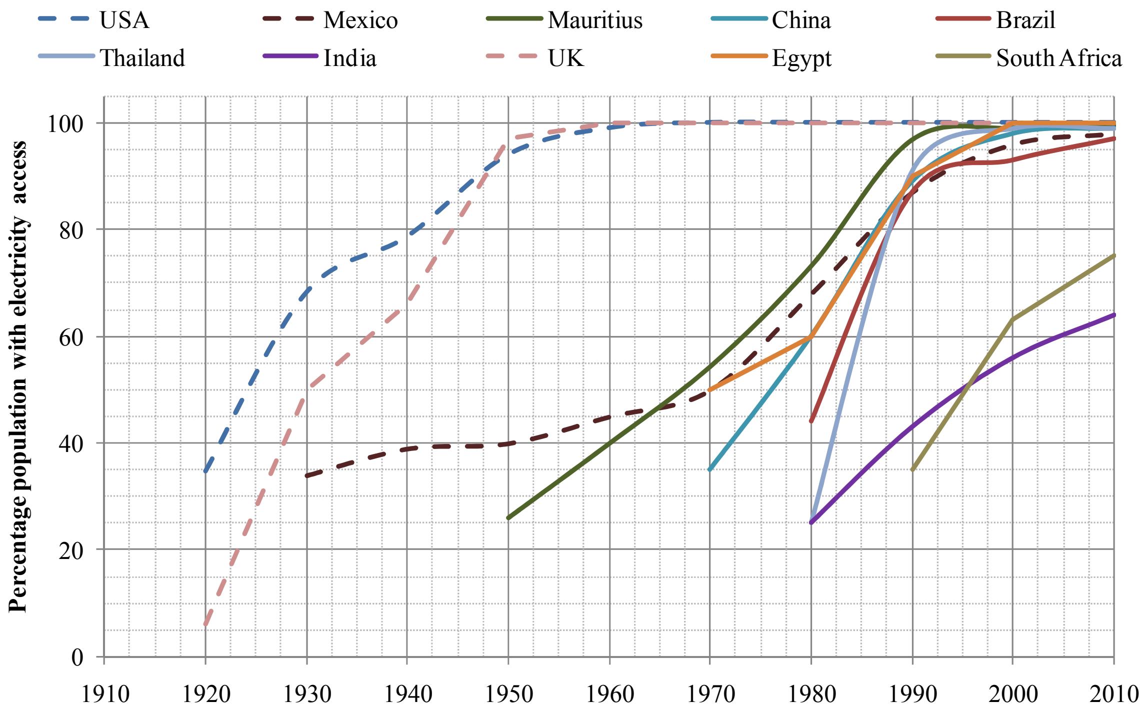


Figure 4-2: Evolution of household electrification over time in selected countries

Source: Pachauri et al. 2012

While several countries in SSA have show dramatic growth (around four-fold) over the last two decades, these mostly started from a relatively small installed capacity. The majority of countries in the region have had sluggish growth, or even a decline in installed capacity. On average, installed electricity capacity in SSA (excluding RSA) grew relatively steadily at around 1.7% per annum. A closer look at the rate of historical growth (or contraction) in African countries (see Figure 4-3) is useful for several reasons. First, it illustrates that there is no discernible pattern of any overall increase of the growth rate over time. One might suppose that with growing recognition of the crucial importance of energy, and electricity in particular, efforts to boost generating capacity would have been more pronounced in recent years. This notwithstanding, there are early signs that some acceleration in the expansion of Africa's generation capacity may be taking place. Data on donor commitments to power projects suggest that during the last five years an annual average of 3 GW of generation projects have been committed. Furthermore, the Annual Report of the Infrastructure Consortium for Africa 2010 notes that member commitments to energy projects in Sub-Saharan Africa rose from USD 1.2 billion in 2006 to USD 8.0 billion in 2010.

Second, whilst it shows high variance[45], the growth rate is generally between 0 and 10%, with the bulk being between 0 and 5%. Third, the variability of the change in installed capacity is high, and is decreasing with time, particularly during recent years. And fourth, the graphical representation indicates that larger systems (depicted as red dots in the Figure) (that is, countries with greater existing capacity and transmission and distribution grids), tend to expand their capacity faster than do countries with medium and small electricity systems. In fact, with few exceptions countries with smaller electricity systems (dots in blue in the graph) have relatively low growth, or even sometimes negative growth, particularly at the end of the 1990s.

[45] Rate ranging from -50% to +157%.

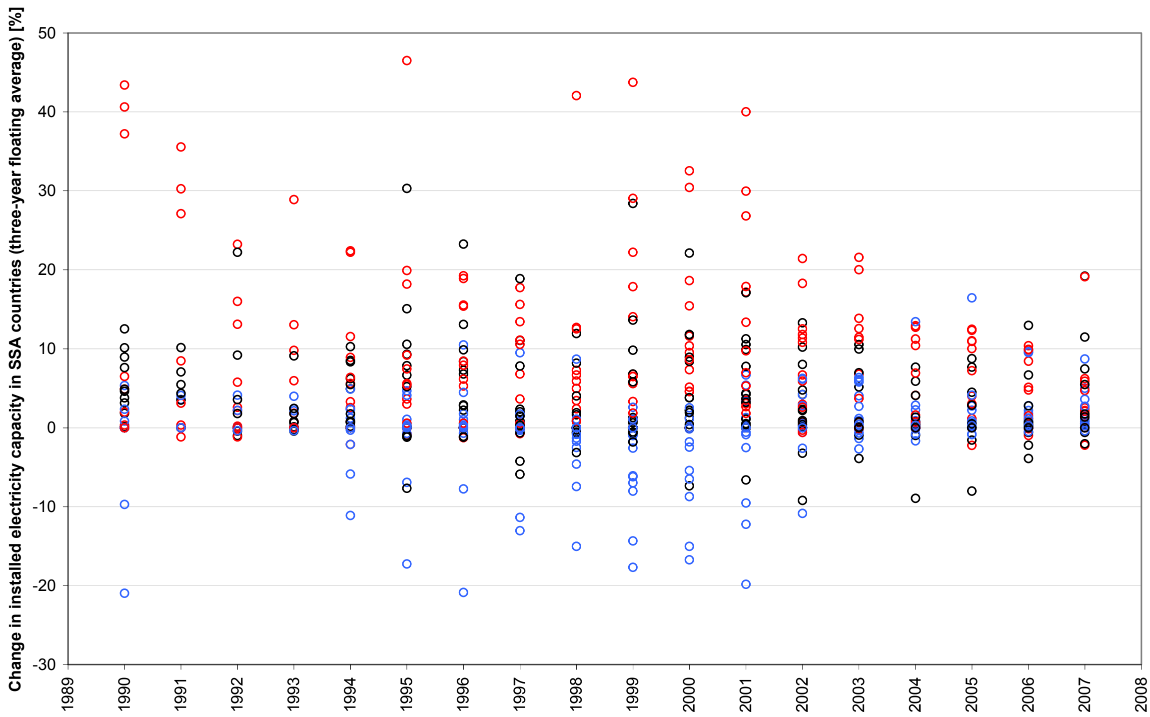


Figure 4-3: Rate of increase (or decrease) in installed electricity capacity (with three year floating average) in SSA countries arranged by tertile

Note: (red, black and blue dots features countries with relatively large, medium, and small generating capacity, respectively, in 2008). Data: authors' compilation from EIA.

4.4. Outlook for Africa

4.4.1. Existing electricity demand projections

In this section, we briefly consider some of the data sets and projections for the power sector in Africa. For an initial sense of scale, using EIA data, Africa has a current installed generating capacity in 2008 of about 122 GW, SSA had 75 GW, and SSA (excluding RSA) had 31 GW[46]. This compares roughly to 28 GW in Argentina in the same year.

- Africa is included in the major energy outlooks from the International Energy Agency (IEA), the US Department of Energy's Energy Information Agency (EIA), British Petroleum (BP), and others. Each data set has different levels of descriptive information, coverage, and aggregation[47]. We primarily relied on the EIA data set as it was the most transparent and complete in terms of accessible country time-series data. It is useful to look at results of these high-level global modeling exercises to get a sense of the numbers being fed into the 'global energy dialogue'.

  As an example, IEA (2010) projects total installed capacity for all of Africa at between 270-291 GW in 2030. Depending on one's assumptions about the ratio of SSA and RSA to the African continent, these figures imply approximately 70-80 GW in SSA (without RSA) in 2030.

[46] Thus, SSA accounts for about 61% of the African continent's total installed electricity capacity (RSA is, in turn, about 59% of the resulting SSA figure). SSA is approximately 1.7% of the world total installed electricity capacity (0.6%, excluding RSA). We use these ratios to derive SSA figures (and SSA excluding RSA) from scenarios that normally treat the African continent as a whole.

[47] These three sources generally are well aligned in their historic data with the EIA figures marginally lower than IEA and BP, likely for reasons of accounting around imports and exports.

- Most of the African sub-regions have carried out forecasting exercises for peak energy demand[48], commonly both in terms of peak demand (or generation capacity) and consumption (or generation) (see e.g., Nexant 2004, 2009). Those projections are normally based on studies conducted at the national level. Despite forecasting methods that vary considerably, the regional plans and related documents entail a wealth of quantitative information that is all too often underutilized in further analysis and planning.

  The New Partnership for Africa's Development (NEPAD), Southern African Development Community (SADC), the Forum of Energy Ministers in Africa (FEMA), Economic Community Of West African States (ECOWAS), East African Community (EAC), and the Commission de la Communauté Economique et Monétaire de l'Afrique Centrale (CEMAC), amongst others, have produced strategies for electrification and increasing access to modern fuels.

  A closer look at some of the regional forecasts in the interests of comparison is useful. A SAPP electricity demand forecast to 2025 shows a projected annual growth of about 2%; the annual growth rates are projected to be higher outside RSA. Nexant (2004) shows projected WAPP average growth to 2020 of 7.6% (ranging from 5-12.6%). The EAC/EAPP Demand Forecasts (SNC Lavalin 2010) show very large ranges in forecasted annual growth. They provide very detailed analysis of each country's national forecasts and then extend them to 2038 where appropriate. Interestingly, the forecasts for many of the countries show the same kind of exponential growth we explore in Section 5 in their 'high' scenarios, and reflect more typical trend or regression-based forecasts for "low and base" cases (SNC Lavalin 2010). Figure 4 shows, as an example, the forecast to 2038 (in MW) for peak demand in Kenya, including showing sharp growth in the "High Case" from 1 GW to over 18 GW to 2038.

- Eberhard et al. (2011) develop several scenarios to 2015 for Africa. They considered three types of demand: market, suppressed and social to help create three scenarios (constant access, regional target and national targets). The overall average annual electricity demand growth rate was estimated at 5.8%.

- The objectives of the Study on Programme for Infrastructure Development in Africa (PIDA)[49], due to be finalized in early 2012, are to enable African decision-makers to, *inter alia*, establish an infrastructure development programme articulated around priorities and phases and, prepare an implementation strategy and process including, in particular, a priority action plan.

  The peak demand projections from initial PIDA (for the African continent) shows an average 6.7% growth (with regional annual growth rates ranging from about 6-9%) over the period 2009-2040. The initial results assume that the access rate will increase from 42% in 2009 to 65% in 2030; these rates are projected to be similar in 2040.

- The Global Energy Assessment (GEA) developed global energy scenarios that include universal energy access by 2030 as one of the normative objectives (Riahi et al. 2012). As part of this effort, a detailed access modeling within the MESSAGE[50] model framework focuses on the key world regions where the lack of access is currently the most acute, including all of sub-Saharan Africa.

- The African Development Bank (2008) undertook a universal access scenario assessment through 2030. The results that without South Africa the total equals 102 GW – approximately an average of 6% annual growth.

[48] To compare to those studies that consider peak demand, a heuristic can be employed by decreasing these figures by 10%.

[49] More information at: http://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/programme-for-infrastructure-development-in-africa-pida/.

[50] Model for Energy Supply Strategy Alternatives and their General Environmental impact (Messner & Strubegger 1995; Riahi, Grübler & Nakicenovic 2007).

Each of these exercises uses different country coverage, different sector definitions, varying underpinning assumptions, etc. For this reason the figures are difficult to compare and thus, difficult for policy-makers to understand as complementary pieces of information.

4.4.2. Generation technology portfolios

In this sub-section, we take a closer look at the various projections in terms of technology and energy sources.

Eberhard et al. (2011) report that over 900 TWh (approximately 220 GW installed capacity) of economically viable hydropower potential in Africa remains unexploited, located primarily in the Democratic Republic of Congo, Ethiopia, Cameroon, Angola, Madagascar, Gabon, Mozambique, and Nigeria. Similarly, the Intergovernmental Panel on Climate Change (IPCC) estimates the technical hydropower potential at 1174 TWh (or 283 GW of installed capacity), only eight percent of which has been developed. Interestingly, this unused potential is about ten times the current installed generating capacity in SSA if RSA is excluded. Tapping hydropower sources could help greatly in achieving full access as we discuss in Section 4.5.

The newly formed International Renewable Energy Agency (IRENA) is now designing future renewable energy scenarios. The focus of their work will be on providing detailed, regional specific technology information with a clear focus on renewable energy. Table 3 also indicates that the technical potential for renewables is enormous, and largely untapped, in Africa (IRENA 2011). The accounting of biomass remains contentious; still, even using conservative assumptions, the potentials are significant.

Table 4-2: Technical potential for renewable energy in Africa by region

Region	Wind [TWh/yr]	Solar [TWh/yr]	Biomass [EJ/yr]	Geothermal [TWh/yr]	Hydro [TWh/yr]
East	2 000 – 3 000	30 000	20 – 74	1 – 16	578
Central	-	-	49 – 86	-	1 057
North	3 000 – 4 000	50 000 – 60 000	8 – 15	-	78
South	16	25 000 – 30 000	3 – 101	-	26
West	0 – 7	50 000	2 – 96	-	105
Total Africa	5 000 – 7 000	155 000 – 110 000	82 – 372	1 – 16	1 844

Source: IRENA (2011). Note: the reference also includes the full sources for each estimate

In Figure 4-4, we use a ternary graph to plot selected (international organisation) projections in terms of electricity production in Africa by types of energy sources, namely coal and oil, renewables, and low-carbon (nuclear and gas)[51]. Such representation allows visualizing the foreseen transition in the electricity generation and corresponding technological and resources shift. The portfolio of generation types critically impacts power system design and operation (including the amount of total installed capacity required because of issues such as intermittency, ramping rates, and inertial response). All of the projections foresee a decrease, in relative terms, of carbon-intensive resources in Africa in the coming two decades, including those scenarios without an explicit focus on climate change mitigation. Also, most projections feature an increase in low-carbon technologies in a first phase, before the share of renewables picks up significantly[52].

[51] The data of the GEA could not be directly compared because of the different regional definition. In addition to international organisation projections there are, of course, sub-regional and national scenarios that consider different generation portfolios (see e.g., Nexant, 2009).

[52] It is interesting to note that the EIA projection contrasts with the others in that the share of renewables remains stable or decreasing over time; only the share of low-carbon options increases. EIA's renewable electricity projections are based on the expected value of the current policies – the stated target (either capacity or generation) multiplied by an assumed probability of achieving that target. Comparing the EIA to IEA's WEO 2010, it appears that EIA's hydroelectric projected growth rate is similar to IEA's while wind, solar, geothermal, and biomass growths rates are much lower. IEA seems more

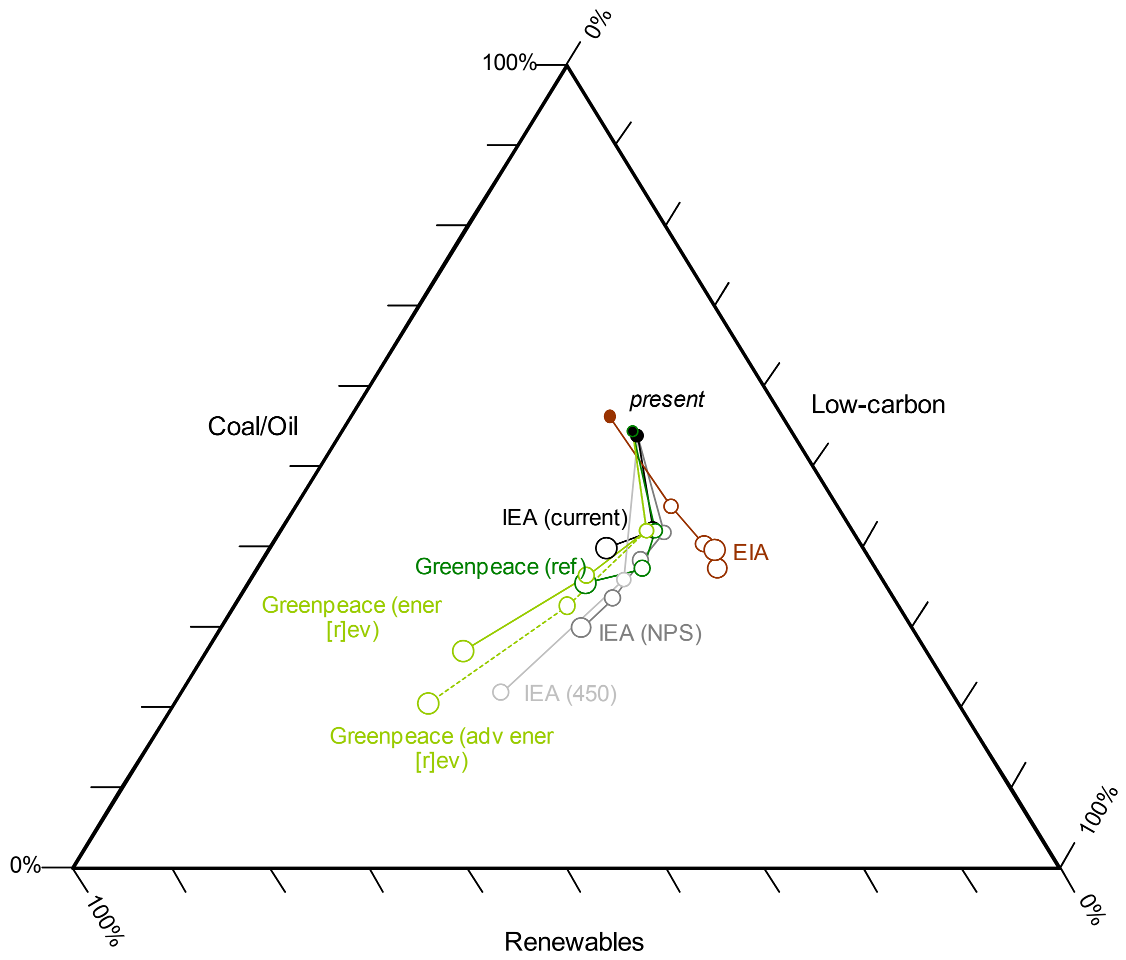


Figure 4-4: Various projections of electricity generation in Africa by types of by different organisations, 2010-2030

Note: the size of the dots is proportional to the total electricity generation projected; with present estimates (filled dots), estimates in 2030 (last dot of each scenario), and intermediary estimates. Data: own compilation from IEA (2010b), EIA (2010), and Greenpeace (2010).

4.5. Simple Scenarios to 2030

4.5.1. Scenarios

Using simple heuristics, we calculate 'back of the envelope' electricity generation capacity required in SSA (excluding RSA) to 2030 under various electricity access level assumptions (see Table 4-3). It is important to note that these scenarios are not limited to household demand, but for the entire economy. In the first two scenarios we separate the number of people without access (electricity poor) from those with access (non electricity-poor)[53], and each category arrives at a different level of access in 2030. In the two other scenarios the entire 2030 population is brought to a single average level of access. Of

optimistic about non-hydroelectric renewables deployment than EIA. EIA assigns low probabilities to non-hydro renewable projects and policies in Africa because of the lack of historical support for these options. Hydroelectric power plants, however, have been successfully built in Africa for many years.

[53] Population growth forecasts are taken from World Population Prospects: The 2008 Revision, United Nations Population Division, UNDATA; *medium variant* scenario. We use the electrification rate forecast from the IEA (NPS) scenario which leads to 640 million without access in 2030.

course, such results are highly stylized and would, in themselves, not properly consider issues such as: intermittency of various energy sources, load factors, reliability, availability, interconnection, system operation, ramping, etc.

The results of this exercise are astonishing in terms of the required growth rates and installed capacity. As an example, just to reach the our *Moderate Access* case where the population has between 200-400 MW/mln requires a total of around 374 GW of installed capacity – about twelve times current levels. This implies around a 13% annual growth rate for the next 20 years as compared to 1.7% for the past 20 years. The other scenarios show that bringing access to the projected SSA (excluding RSA) population in 2030 would take approximately 500 GW to reach an average of 400 MW/mln (*Full Access*) and to reach 800 MW/mln (the current rate of RSA – *Full Enhanced Access*) would double this requirement. We recognise that our results assume much higher levels of access than much of the literature that focuses solely on 'basic needs' at the household level[54].

Table 4-3: Estimates for installed electricity generation capacity required (in GW) in SSA (excluding RSA) under various access level (MW/mln) assumptions

Level of access	2010 [GW]	2030 [GW]	Implied average annual growth rate 2010-2030	Scenario Name
Population - electricity poor, million	573	638	0.5%	
Population - non electricity-poor, million	240	615	4.8%	
electricity poor: 0 MW/mln non electricity-poor: 129 MW/mln	31	79	4.8%	*Business As Usual*[55]
electricity poor: 200 MW/mln non electricity-poor: 400 MW/mln		374	13.3%	*Moderate Access*
full population: 400 MW/mln		501	14.9%	*Full Access*
full population: 800 MW/mln		1,002	19.0%	*Full Enhanced Access*

Figure 4-5 provides a simplified overview of several scenarios as well as projections. In addition to plotting the *Moderate Access* and *Full Access* scenarios from Table 4-3, it includes: a *50% Access* scenario that assumes that 50% of the population will have access at a rate of 400 MW/mln, along with two statistically derived projections based on historical data. *GDP regression* represents a regression analysis using GDP[56] as the independent variable (with double exponential smoothing of historic data), and results in about 70 GW in 2030[57]. The *Trendline* is a historically-based extrapolation, and projects about 43 GW in 2030. We portray the scenario curves as having exponential growth, but of course growth in power capacity will likely be much more 'lumpy' and unevenly distributed.

[54] Thus the term 'moderate' in our scenario.

[55] Maintaining current levels with population growth.

[56] GDP forecasts (in current prices) are taken from the World Economic Outlook database.

[57] For comparison, if the IEA (NPS) figures from the IEA 2010 WEO were first decreased by the 2008 ratio of SSA to Africa (61%), then decreased by the historical rate for SSA (excluding RSA) to SSA (41%), then increased that ratio up to 49% in 2030 and finally decreased by 15% to allow them to be comparable to EIA data; that number would be 71 GW.

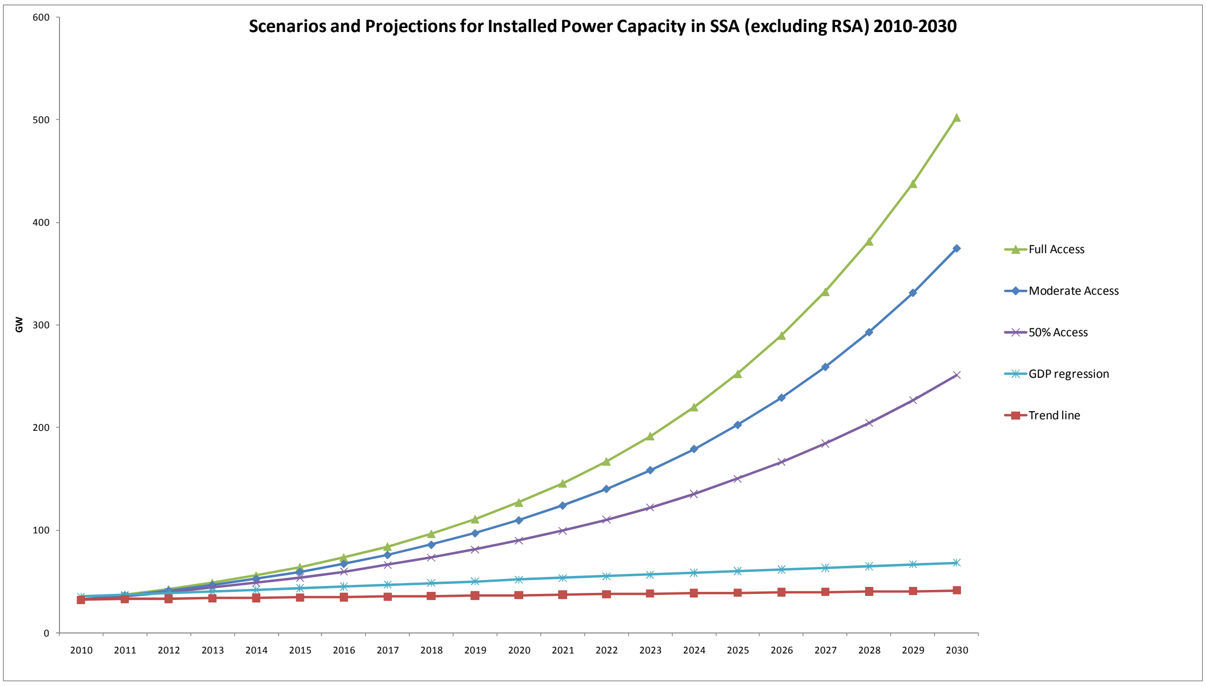


Figure 4-5: Scenarios and projections of installed electricity capacity to 2030 for SSA (excluding RSA)

It is also useful to consider how to 'jump-start' from historic trends to, as an example, the *Moderate Access* case. A few well-designed large projects would allow very high initial growth levels to help give confidence to the sector for an extended period of growth. For instance, the proposed Grand Inga hydroelectric project (in the Democratic Republic of Congo) could reach almost 40 GW in scale. Inga then would, theoretically[58], provide a significant short-term contribution to the additional capacity required. A few such large-scale projects might also provide the necessary impetus for transmission projects. High levels of growth in smaller or distributed generation projects would also likely support the necessary momentum.

Finally, while it is valuable to illustrate what it would mean to meet a target of 100% electrification by 2030, it is also important to acknowledge that this target seems ambitious. Historical evidence seems to imply that a 30-40 years timeframe is likely a more realistic range, particularly given the following considerations:

- The final segment from 90%-100% access is necessarily slower due to increasing marginal costs and technical difficulties, as Figure 4-2 bears out.
- Historical precedent, as reported in Figure 4-2, describes single country achievements; whereas for Africa to meet the universal electrification target, nearly 50 countries would need to do so simultaneously.

On an average annual basis then, SSA (excluding RSA) must add about 23 GW per year in additional capacity – equivalent to a little more than a Three Gorges Dam (22.5 GW) sized project each and every year through 2030.

4.6. Conclusions

Almost every country in SSA has produced forecasts and a roadmap (some with explicit targets for access) for their power sectors - building on these is essential. To that end, and to give a high-level perspective for the benefit of the international community, we have outlined several simple, transparent scenarios for the power sector in sub-Saharan Africa. They employ a highly simplified methodology to provide a sense of scale of the growth challenges inherent in working towards universal access to

58 Again, of course issues of transmission and the like would make this thought exercise highly abstracted. Recent reviews from the World Bank suggest about 30 GW of large hydro projects in the SSA region are feasible in the next 10 years.

electricity services. Still, it is recognised that 'bankable' policy and investment decisions necessitate more detailed and complex analysis and planning down to the level of individual power plants and related transmission and distribution infrastructure. There is clearly much room for further, more detailed analysis in this area.

Despite a host of information regarding obstacles to universal access to energy services, and various proposals for financial, regulatory and other tools to address them, understanding the immense scale of the endeavour is necessary to provide a context for, and help guide policy-making. The exercise also provided some clarity on several key analytical assumptions that drive power system planning, such as growth rates and mid-term access goals.

It is clear that most projections from international organisations, regional entities, national governments, and power companies foresee growth rates in generating capacity on the order of 6-8% annually – in line with GDP forecasts – and typical demand forecasting techniques. While these are dramatic increases over historical rates, and would result in installed capacities of about three times current levels in just two decades, they are insufficient to meet even modest definitions of universal access. We presented several easily-replicated scenarios that demonstrate the need for at least ten times more installed capacity than today by 2030 (implying sustained average annual growth rates of around 13%). Some kind of 'jump-start' is likely required to move the growth pathway onto this trajectory. The role of the international community is best employed to help encourage the cooperative movement of the disparate pieces towards a common goal.

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5. Understanding the Scale of Investment for Universal Energy Access

5.1. Introduction

A significant share of the world's population lacks access to the services provided by modern energy. Approximately 1.4 billion people do not have access to electricity (IEA, UNDP & UNIDO 2010), and about 3 billion people rely on solid fuels for cooking (UNDP & WHO 2009). Reliability of existing supply is also often problematic. Focusing on Africa's infrastructure, Foster and Briceno-Garmendia (2010) claim that the continent's chronic power problems (e.g. inadequate generation, limited electrification, unreliable services, and high costs) significantly affect economic growth and productivity.

The international community has recognized the importance of the matter for development, and there has been a recent call for a global target of universal access to energy services by 2030 (AGECC 2010). Yet, despite current efforts, progress in delivering energy access is inadequate. In addition to a global political commitment (Bazilian, Sagar, et al. 2010), investment and appropriate financial tools for energy access are needed to address the issue. We consider only the initial step in this complex agenda, namely the total cost of providing universal energy access.

A number of estimates of the cost of providing universal energy access in developing countries have been produced. The methodologies and assumptions vary greatly and are generally simplistic[59]. Most studies do not provide a holistic picture, but rather focus on specific aspects, such as the capital cost of energy supply. This paper reviews the literature and attempts to 'untangle' the numbers to provide a transparent basis for comparison. It then presents new insights with regard to the breakdown of the cost of universal energy access, a simple new methodology, and a resultant estimate.

Calculating large global investment requirements is a difficult task and relies on a number of assumptions; still, it is often a useful benchmark for policy making and international diplomacy. It is also useful for providing context for the design of financial responses. Useful precedents, at least at a conceptual level, can be drawn from similar exercises carried out in the climate change space. As an example, the United Nations Framework Convention on Climate Change (UNFCCC) commissioned a report on the scale of future financing options (UNFCCC 2007). The document includes a literature review of estimated annual investment needs for both climate change mitigation and adaptation. Those estimates were then fed in to support various governmental decision making processes.

We recognize that a solid enabling environment (including capacity building and institutional strengthening) and appropriate investment climates linked to adequate policies and regulations are crucial to delivering adequate financing for energy access. However, such considerations are beyond the scope of this paper (see e.g., Morris et al. 2007; Morris and Kirubi 2009). It is also clear that the availability of capital is a necessary but not sufficient condition to deliver energy access; the treatment of financial tools is also beyond the scope of this paper, as are the sources of funding.

We begin by reviewing cost estimates related to providing access modern energy services published in both the 'grey' and academic literature. Section 5.2 provides an overview of existing estimates, including an examination of their scope and an attempt to disaggregate them for the purposes of comparison. Section 5.3 presents our own estimates. In section 5.4, we discuss further areas of work and possible next steps for increasing the rigour of these estimates.

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[59] Specifically, here the term 'simplistic' refers to the use of linear multiplication algorithms based on a limited set of highly-aggregated and averaged parameters and assumptions.

5.2. Literature Review

5.2.1. Existing estimates

Several estimates have been made of the cost of universal access to modern energy services at the global, regional, and project levels. They focus on various aspects of energy poverty (e.g. electrification, clean cooking). A non-comprehensive review of these is provided in Table 1. It shows a wide variation in estimates, providing the impetus to consider further the underlying algorithms and assumptions.

Table 5-1: Cumulative (unless otherwise stated) investments to facilitate access to modern energy service, in billion USD

		Cost estimates [billion USD]				
Geographical focus	Goal	*Electricity*	*Cooking*	*Others*	*Period*	Source
Global	Universal energy access	700[i]	56		2010-2030	(IEA, UNDP & UNIDO 2010)
	Improved access to reach MDG 1	223	21[ii]		2010-2015	(IEA, UNDP & UNIDO 2010)
	Universal energy access	35-40 per year[iii]	39-64[iv]		2010-2030	(AGECC 2010)
	Universal electricity access	~55 per year				(Saghir 2010)
	Universal electricity access	35 per year			over 2008-2030	(IEA 2009b)
	Improved access to clean cooking[v]		1.8 per year		to 2030	(Birol 2007)
	Universal electricity access[vi]	858			2005-2030	(The World Bank Group 2006)
	Improved electricity access to reach the MDGs	200			over 2003-2015	(IEA 2004)
	Universal electricity access	665			over 30 years	(IEA 2003)
Regional/local						
Africa	Improved electricity access[vii]	17 per year[viii]			to 2030	(AfDB 2008)
Sub-Saharan Africa	Improved energy access	6-15 per year				(Brew-Hammond 2010)
	Increase household electricity access to 35%	4 per year			to 2015	(UN-Energy/Africa undated)
East African Community	Improved energy access[ix]	1.5	0.262	0.919	to 2015	(EAC 2006)[x]

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[i] Including both rural and urban; grid connection: generation and transmission & distribution; mini-grid: generation and distribution; off-grid: generation.

[ii] Including advanced biomass stoves, LPG stoves and biogas systems.

[iii] Based on IEA (2009a).

[iv] Improved cookstoves: 11-31; Biogas: 30-40; LPG: 7-17; Includes capacity development costs.

[v] LPG cylinders and stoves to all the people who currently still use traditional biomass.

[vi] Includes breakdown by major regions.

[vii] Reliable electric power to 90% of sub-Saharan rural population, 100% of the sub-Saharan urban population, and 100% of the both the rural and urban populations in the Northern African middle income countries.

[viii] Considering only new generating capacity, including generation as well as transmission and distribution.

[ix] Reliable electricity for all urban and peri-urban poor; Modern cooking practices for 50% of population currently using traditional cooking fuels; Modern energy services for all schools, clinics, hospitals, and community centres; and mechanical power for heating and productive uses for all communities.

		Cost estimates [billion USD]				
Geographical focus	**Goal**	***Electricity***	***Cooking***	***Others***	***Period***	**Source**
Economic Community of Central African States	50% electrification	1.45			over 10 years	(CEMAC 2006)
Economic Community of West African States	60% electrification; 100% improved cooking fuels; access to mechanical power in 100% of villages	2.1	2.8	0.27[xi]	over 10 years	(ECOWAS 2005)
South Africa	Electrification	1000 USD per connection[xii]				(Eskom 2009; IEA 2009a)
Kenya	Electrification	1900 USD per household[xiii]				(Parshall et al. 2009)
Botswana	Electrification	1100 USD per household[xiv]				(Krishnaswamy & Stuggins 2007)
Mali	Rural electrification	776 USD per connection[xv]				AMADER quoted in (Foster & Briceno-Garmendia 2010, p. p. 199)
Senegal	Increased electrification rate from 47 to 66%	0.86			Over 10 years	(ASER 2007)
Bangladesh, Cambodia, Ghana, Tanzania and Uganda	Improved energy access in line with the MDG targets	13-18 USD per capita and year[xvi]			over 2005-2015	(Sachs et al. 2004)
South Asia	Universal access to LPG		449		2010-2030	IIASA[xvii]
Brazil	Promoting LPG access to underprivileged households		0.5[xviii]		in 2003	(Jannuzzi & Sanga 2004)

[x] Including capital expenditure, programs, and loan guarantees.

[xi] For mechanical power.

[xii] The average is expected to increase as the electrification process moves to communities in more remote rural areas.

[xiii] Average cost per household in a so-called realistic penetration scenario, with USD 1500 and 2615 for infilling and grid extension, respectively; based on modelling of grid extension.

[xiv] Based on project experience.

[xv] Based on project experience from AMADER (Agence malienne pour le développement de l'énergie domestique et l'électrification rurale).

[xvi] Including costs of: end-use devices, fuel consumption, electrical connections, and power plants.

[xvii] Updated analysis based on the methodology described in Ekholm et al. (2010).

[xviii] Subsidies for LPG access to underprivileged households in 2003.

		Cost estimates [billion USD]				
Geographical focus	**Goal**	***Electricity***	***Cooking***	***Others***	***Period***	**Source**
(unspecified)	Electrification	above 1200 USD per connection[xix]				(Practical Action undated)

Not included in Table 5-1 is the World Bank's model for the Africa Infrastructure Country Diagnostic Initiative (The World Bank Group 2010). The model is available through a web interface which allows the user to alter major assumptions, including urban and rural access rates, and calculate spending needs for a number of African countries and compare them against a baseline. It will likely be a useful tool for further estimates in the future.

[xix] New connection to electricity; based on case studies; varies from country to country, and can be as much as 6000 USD in some cases.

In general, the reviewed estimates focus on the provision of electricity. A small number consider clean cooking, but other services such as mechanical power or transport receive very limited attention. Global estimates have been produced primarily by international organizations, while academia, regional institutions and utilities have commonly focused on the regional and national scales. The figures have been produced using methodologies that range from analytical modeling to extrapolation of empirical results.

5.2.2. Comparing the estimates

Quantitatively comparing the estimates is challenging for a number of reasons. First, the underlying methodologies and assumptions vary greatly. Second, the information required to make the estimates comparable is often not available. And third, the different studies vary widely in terms of their ambition and scope. To contend with these obstacles, we utilise a common denominator (per capita[79] annual average or per connection).

5.2.2.1. Electrification costs

Figure 5-1 compares estimates of average annual cost per capita for electrification, split between capital costs, operation and maintenance (O&M), fuel and others (e.g. capacity building) when explicitly available.

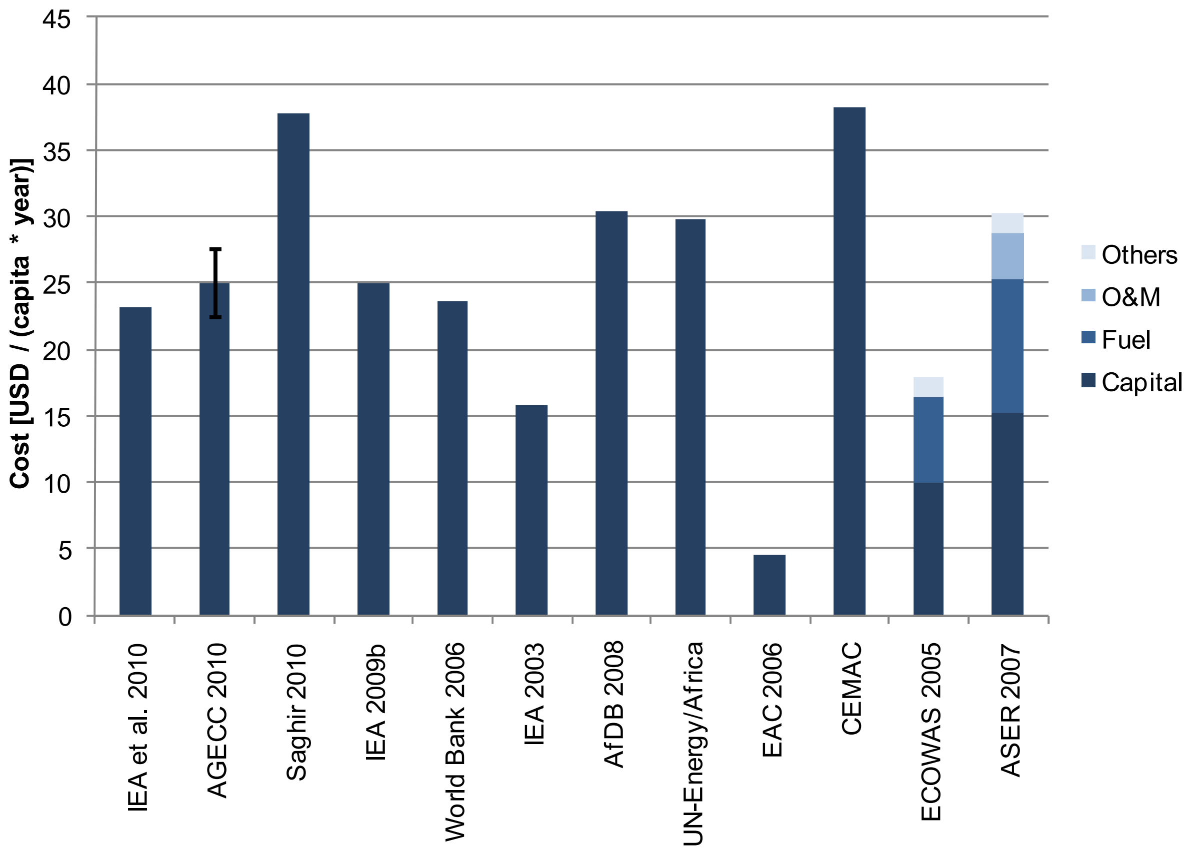

Figure 5-1: Comparison of cost estimates for electrification

The estimates of annual costs for capital investment for electrification range from 5 to almost 40 USD per capita, reflecting the large uncertainties associated with such evaluations (and the sensitivity to certain assumptions). One important insight is that the majority of studies focus solely on capital cost

[79] Although considering the household as a unit would be more appropriate in the case of providing energy to the poor, using per capita figures allows to avoid further assumptions with regard to the typical size of household, which varies greatly between countries, e.g. Cameroon: 2.9; Guinea-Bissau: 7.6 (data source: Banerjee et al. (2008)).

and do not consider recurrent (or ongoing) costs (e.g. fuel, O&M), with the notable exceptions of ECOWAS (2005) and ASER (2007).

The IEA estimates are the most often cited in the literature (either directly or in a circular fashion), and have been relatively consistent over time[80]. They are also one of the few sources that provide investment estimates at both the global level and disaggregated by regions. A cumulative USD 700 billion is estimated to be required for universal electricity access by 2030 provided that appropriate policies are in place (IEA 2009b; IEA, UNDP & UNIDO 2010). This implies an investment of some USD 33 billion per year on average over the coming two decades. IEA analysis also provides insights with regard to the breakdown between generation, transmission and distribution (T&D) (IEA 2003 2009b). Using the relationship between poverty and modern energy access, the IEA also produced a scenario that is consistent with the achievement of the Millennium Development Goal of eradicating extreme poverty and hunger (MDG 1) by 2015. This MDG scenario requires cumulative investment of some $223 billion from 2010-2015, representing around 30% of the cumulative investment needed to achieve universal electricity access by 2030 (IEA 2004; IEA, UNDP & UNIDO 2010).

5.2.2.2. Connection costs

Several publications provide insights with regard to electricity connection costs (another possible comparator). While a number of the estimates are based on modeling work (e.g., Parshall et al. 2009), others rely on data from project experience (e.g. Eskom 2009). The latter provide a reliable source of information as they are not biased by normative assumptions and methodological shortcomings, but are arguably unsuitable for extrapolation due to their context dependency. The modeling estimates are informative in that they can allow a better understanding of the cost drivers associated with electrification. Figure 5-2 provides an overview of the electricity connection cost in the studies reviewed.

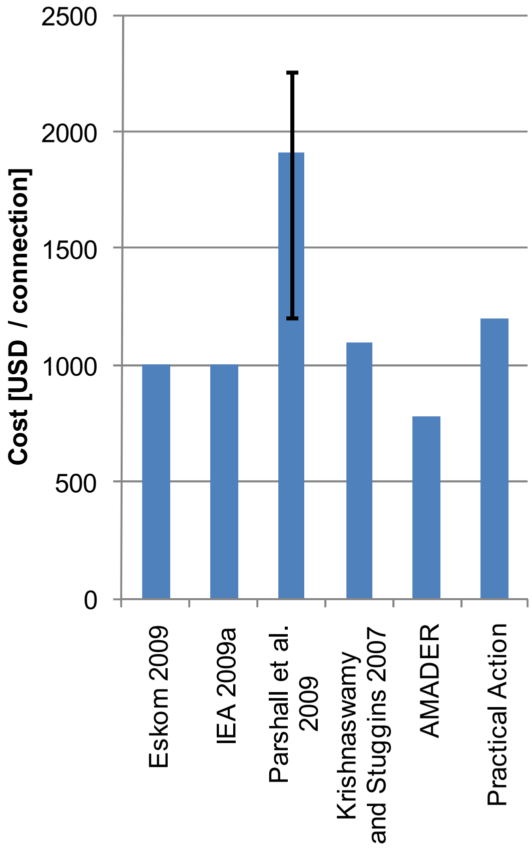

Figure 5-2: Comparison of connection cost estimates

[80] The IEA has produced authoritative quantitative information on energy access for almost a decade.

Connection costs published in the literature (and by utilities) vary considerably due to a number of factors, including the capacity of the connection[81]. In addition, various publications underline the fact that the marginal cost of connections increases as the electrification process moves to more isolated and geographically challenging areas[82]. In contrast, when considering economies of scale, the per-beneficiary cost can be expected to decrease compared to estimates based solely on extrapolation of empirical evidence from isolated projects.

5.2.2.3. Clean cooking costs

As in other areas, the estimates reviewed for clean cooking again show wide variations (see Table 5-2), with some consistency between studies considering capital cost exclusively. The breakdown is insightful in that it demonstrates that fuel costs are assumed to be at least as large as capital costs. ECOWAS (2005) and IIASA's estimates, which include fuel costs, are thus significantly higher than other studies. The context dependency of the estimates must be underlined, and the fact that some studies focus on specific regions and/or type of fuel explains some of the variance.

Table 5-2: Comparison of cost estimates for clean cooking

Cost estimates [USD / (capita*year)]		
Capital	*Fuel*	Source
1.0		(IEA, UNDP & UNIDO 2010)
0.9		(AGECC 2010)
0.6		(EAC 2006)
1.3	8.3	(ECOWAS 2005)
5.0	18.1	IIASA[83]

The IEA et al. (2010) cooking estimates include investment in advanced biomass cookstoves, LPG stoves and canisters, and in biogas digesters, but exclude investment in infrastructure, distribution and fuel costs. Country/regional breakdown of the investment is derived from assumptions regarding the most likely technology solution in each region, given resource availability and government policies and measures.

Comparing the estimates across various energy services, the per capita cost for clean cooking is significantly lower than that for electrification. With regard to mechanical power, the paucity of data precluded our analysis.

5.2.3. Gaps in the estimates

We have identified several gaps in existing cost estimates. Many studies consider only one of the energy delivery 'vectors'. Also, most estimates give less attention to recurrent costs such as O&M and

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81 For comparison, the Durban municipality is charging a fee of USD 935 for a single phase connection, and between USD 1,923 and 92,457 for a three phase connection. Data source: http://www.durban.gov.za/durban/services/electricity/tariffs/schedule-of-connection-fees-and-charges-2010-2011. Similarly, Hydro Québec charges from USD 1,312 per individual house for a basic connection. The price rises based on the scale of demand. Data source: www.hydroquebec.com/publications/en/rates/pdf/frais_service.pdf.

82 In that regard, Parshall et al. (2009) apply a spatial electricity planning model to estimate the cost of connection in various contexts in parts of Kenya and found that it varies greatly between settlements around major cities and more isolated rural areas.

83 Based on data obtained in personal communication with Shonali Pachauri (IIASA) which stem from updated analysis relying on the methodology described in Ekholm et al. (2010).

fuel costs, with a few notable exceptions (e.g., ECOWAS 2005; The World Bank Group 2010). IEA (2010b) estimates the cost of fuel to represent a significant share (one quarter for coal and up to two thirds for gas) of the total cost in the case of fossil fuel based power generation, while O&M represents between 5-10% of the total cost for fossil fuel and up to 20% for renewables. Those fractions can be much higher for inefficient rural generation. Regardless of the exact figure, the total cost of providing electricity to the poor will be significantly higher than estimates based on initial capital expenditure alone.

5.3. Estimating the total costs of energy access

Using available data and methods we present a new and simple algorithm and from it estimate the cost of meeting universal electrification by 2030. We focus primarily on electricity because of the data challenges described previously. The methodology is highly stylized, but aims to be useful in terms of transparency, comparability and as a basis for more sophisticated estimates in the future. We then consider cooking costs and present a total figure for both service areas.

5.3.1. Methodology

We base our calculation on the full levelised costs[84] of generation as a means of capturing, beside capital costs, costs related to O&M and fuel. We recognize the shortcomings of levelised cost estimates (see Bazilian and Roques 2008) for energy planning, but for this purpose they enable a sufficient and transparent calculation tool. To account for some of the uncertainty associated with such estimates, we present three scenarios (named: low, medium, and high) and use a static linear model to calculate the total cost of electrification.

The primary assumptions include: electricity consumption levels, the types of systems used for electrification (i.e. grid connected, off-grid, etc.), and the levelised costs of generation, for which we use IEA data as the primary source of information. Average levels of electricity consumption are assumed to be different for rural and urban population categories (see Table 5-3). The low scenario assumes electricity consumption levels to fulfill basic needs, as per the IEA's universal electricity access scenario (IEA 2009b, p. 132). The medium scenario depicts a case where some electricity is available for other purposes, including basic productive (economic) activities. The high scenario differs from the medium one in that the rural electricity consumption is assumed to be equivalent to the current average residential use in Latin America[85], and the cost of fuel (fossil and nuclear) is 20% higher.

Table 5-3: Assumptions on rural and urban average consumption in each scenario

	Scenario			
Assumption	**Low**	**Medium**	**High**	**Unit**
Average urban electricity consumption	100	456	456	kWh / (capita*year)
Average rural electricity consumption	50	152	360	kWh / (capita*year)

Data source: IEA (2009a); Banerjee et al. (2008); IEA (2008); Parshall et al. (2009); and own estimates

We use the 2008 IEA electrification data as a baseline, and retain the differentiation between urban and rural population. Urban consumers are assumed to be provided through a grid connection. For rural communities, we arbitrarily assume shares of grid extension, mini-grids, and off-grid systems for each scenario as slight variations from the model outcome of IEA (2009a)[86] (see Annex 5-A). Based on this, we calculate the electricity needs per country in both urban and rural contexts, and estimate the

[84] Levelised cost is a notion that is used for comparing the unit costs of different technologies under a number of assumptions (e.g. absence of specific market or technology risks, specific discount rate, load factors). It includes capital costs of generation, O&M and fuel costs. For the purpose of this analysis, a discount rate of 10% is used.

[85] 360 kWh. For reference, it is 2379 kWh in average in the OECD and 7636 kWh if considering the total final consumption.

[86] Shares of rural electrification through grid: 0.61; mini-grid: 0.34; and off-grid: 0.05.

costs using levelised costs per generation type in four major regions, namely Africa, Asia, Latin America, and the Middle East.

The levelised costs are derived from the literature (ESMAP 2007; IEA 2010a) and adjusted. Specifically, we revisit the fuel cost estimates in ESMAP (2007) in light of considerably higher than expected oil prices. We separate the fuel price expectation into fixed and variable components, and replace the original oil price assumption, taken from IEA (2005), with an average expected oil price of USD 100/bbl from 2010-2030 for the low scenario and USD 90/bbl for the medium and high scenarios to take due account of the lower oil price because of the fact that the demand is lower than in the reference scenario. The oil prices are based on figures from IEA (2009a). In addition to this, we include a factor of 20% to take due account of power delivery losses[87].

For the low variant of the levelised cost, we use the 2007 mix of energy sources for electricity generation from the IEA. The medium and high variants are based on an energy mix consistent with a stringent climate mitigation scenario, such as the IEA 450 scenario (IEA 2009b). We then calculate the respective weighted average costs for capital, O&M, and fuel for the four world regions. We make assumptions with regard to the energy mix for the generation of electricity for mini-grid and off-grid contexts, and calculate the respective costs in a similar fashion as for grid electricity. An overview of the assumptions regarding levelised costs of electricity generation is in Annex 5-B.

$$C_{tot} = \sum (P_{urb} \cdot E_{urb} \cdot c_{grid} + P_{rur} \cdot E_{rur} \cdot \sum s_{sys} \cdot c_{sys})_{region} \qquad \text{Equation 5-1}$$

With C_{tot}: total annual global cost of electrification, P_{urb}: urban population without electricity in given region, E_{urb}: average urban electricity consumption, c_{grid}: weighted average levelised cost in given region, P_{rur}: rural population without electricity in given region, E_{rur}: average rural electricity consumption, s_{sys}: share of generation type (grid, mini-grid, off-grid) for rural electrification, c_{sys}: weighted average levelised cost in given region based on the respective generation portfolio.

This methodology has a number of limitations. Notably, because of the static nature of the model, population growth is not taken into account. Similarly, the changes in the access rate over time in a case where no additional policy and incentive for energy access are put in place are also not considered. For the same reasons, technology development and learning effects are not accounted for in this analysis.

5.3.2. Results

Our estimates for universal electrification range from an annual 13 to 134 billion USD (see Table 5-4). It is important to note that the cost we present is the total annual cost incurred once all people who do not currently have access to energy are connected. Annual costs will be lower in the interim as people gain access.

Table 5-4: Estimates of universal electrification annual cost in USD billion

Scenario		
Low	Medium	High
13	60	134

The breakdown of the costs per energy system type in different scenarios indicates that over half of the required aggregated cost is for systems based on decentralised generation, regardless of the scenario, with rural mini-grids constituting the major share.

The higher costs in the medium and high scenarios are due primarily to increased electricity consumption. Specifically, increased consumption accounts for 72% of the difference between the low and medium scenarios, with the shift to more mini and off-grid generation accounting for 26%, and greater use of low-carbon energy accounting for 2%. Similarly, increased consumption accounts for

[87] Power deliver losses can vary from 10 to 25% or more (ESMAP 2007).

87% of the difference between the medium and high scenarios, with higher fuel costs accounting for the remaining 13%.

Figure 5-3 shows the share of capital, O&M, and fuel cost in the total cost of electricity for the various systems in the different scenarios.

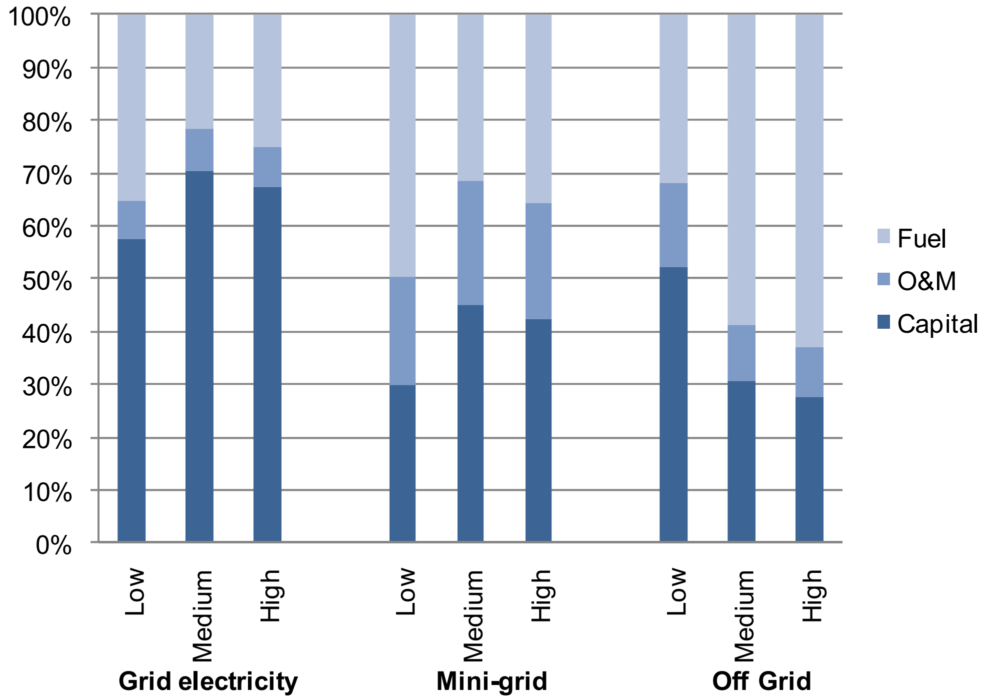

Figure 5-3: Share of capital, O&M, and fuel in the total cost in grid, mini-grid and off grid electricity in the low, medium and high scenarios

Our estimates, as well as a number of the studies reviewed, do not explicitly include costs related to transmission and distribution (T&D). However, the cost of the requisite expansion of T&D is not insignificant. In this regard, IEA (2009a) estimates that T&D costs for grid-connected electricity are roughly equal to the capital costs for generation. Using this proportion as a heuristic, we recalculate the cost of universal electrification with our algorithm to get a sense of the impact and obtain figures that are between 5 (high scenario) and 14 % (low scenario) higher[88].

5.3.3. Towards the total cost of universal energy access

We aggregate the results for both electrification and clean cooking to obtain a high-level total cost figure. With regard to clean cooking, a high degree of abstraction is required. We use global estimates published in the literature and double the cost of capital to take into account fuel costs. Specifically, our reference is the lower and higher bound of AGECC (2010) for the low and high scenarios respectively, and the IEA et al. (2010) for the medium scenario.

Table 5-5 provides an overview of our global cumulative cost estimates for the three scenarios. We assume that the increase in access to electricity is linear until universal access is reached in 2030.

[88] We also note that the omission of T&D in our estimates would slightly alter the share of capital versus operating costs.

Table 5-5: Range of global cumulative cost of universal access to electricity and clean cooking

	Cumulative cost estimates [billion USD]		
Scenario	Electricity	Cooking	Total
Low	134	78	212
Medium	629	112	741
High	1410	128	1538

Figure 5-4 compares our own estimates with recently published other global figures often used and quoted. While our aggregated low estimate is lower than those of IEA (2010a) and AGECC (2010), our high estimate is significantly larger than the other studies.

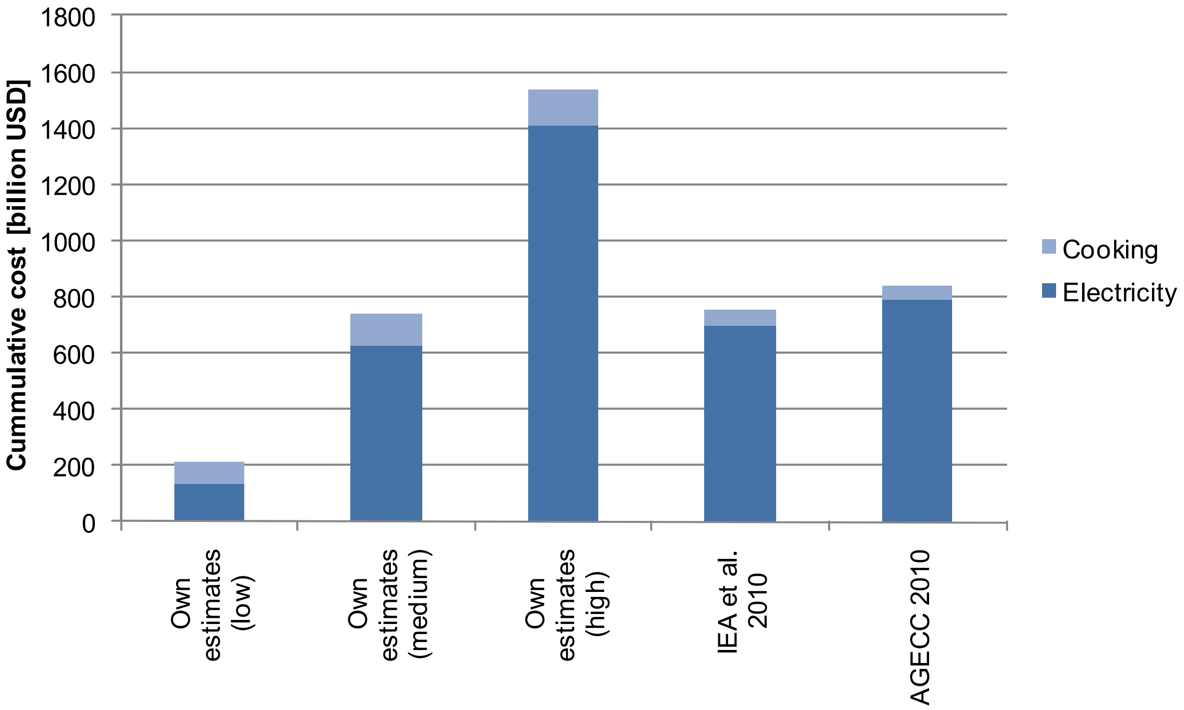

Figure 5-4: Comparison of global cumulative (2010-2030) cost estimates for universal electricity and clean cooking access[89]

5.3.4. Sensitivity analysis on electricity estimates

We undertook some sensitivity analysis of the major assumptions to evaluate the robustness of the findings and identify the key variables. We considered a variation of: the average urban and rural consumption, the weighted average levelised cost for grid, mini-grid and off-grid generation, and fuel costs[90]. The medium scenario is used for this analysis.

The results are presented in Annex 5-C. They indicate, notably, that the average rural consumption has a relatively strong influence on the overall result. The impact of the assumptions regarding the share of different generation systems (grid, mini-grid, and off grid), using the share used in IEA (2009a) as a reference, produced a result 14% higher in the case of the medium scenario.

[89] It is important to bear in mind the different scope and objective of those studies while comparing their outcomes.

[90] The impact on the overall cost is only assessed based on the change in the fuel cost as an element of the levelised cost. Changes in fuel prices would also impact the electricity mix, which is not taken into account in this sensitivity analysis.

5.4. Further work

A number of aspects related to the costing of universal energy access are yet to be thoroughly assessed. This section discusses some elements that deserve further scrutiny and is presented as fodder for further work.

- The operating and fuel costs of traditional devices such as kerosene lamps are often higher than those of modern devices (e.g., solar cells and electric fluorescent lights) (Johansson & Goldemberg 2002). Therefore, transitioning to modern energy services will often actually lessen the financial burden related to energy services of households. In a similar vein, switching to more efficient energy appliances (e.g. compact fluorescent light) also allows countries to reduce investment requirements into additional generating capacity (Goldemberg 1998). In many instances, the cost to improve end-use technologies is more than offset by capital savings due to reduced energy demand (Goldemberg et al. 1985). However, though the marginal benefit of reducing national generating capacity investments are not always realized by the household investing in more efficient appliances. Beside this, efficient appliances may require more upfront capital expenditure, often curbed by sporadic income of the underdeveloped and poor access to credit facilities[91]. Related to this, most of the estimates focus on the supply-side of the energy value chain. However, investments will be required in efficient devices such as modern lighting systems or electrical drives (e.g. pumps) for instance to allow customers to benefit from the energy service. Crude estimates, though, suggest that this additional cost, while significant, does not fundamentally change our overall conclusions, at least at the low end.

  Households typically use basic electrification to operate electric lighting. At higher levels of consumption, many adopt radios and televisions, and, to a much lesser extent, electrical cooking appliances (The World Bank Group 2008). In our low cost scenario, rural individuals are each expected to consume 50 kWh annually. That corresponds to using two 14W compact fluorescent light bulbs for five hours each day. At typical cost of $1 per bulb, and bulb lifetimes of 10,000 hours, this adds a cost of about USD 0.40 per rural customer per year, which adds 4% to our total cost estimate. An urban consumer in this scenario, meanwhile, uses 100 kWh each year, which might involve adding a small shared television. An inexpensive TV costing USD 10 and lasting five years, shared by five people, would add another USD 0.40 per person per year. The total cost of the low scenario would therefore increase by 5% over our estimates.

- With increasing economic activity and standards of living associated with reduced indoor air pollution, better lighting, improved nutrition and access to more productive means, the demand for energy is likely to rise. Such an increase would, in theory, affect the price of energy by driving it up. This effect has not been taken into account in this analysis. Along those lines, IEA et al. (2010) argue that primary energy demand would rise by less than 1% due to universal energy access for basic needs. In the longer term, more significant increase in the energy demand – not accounted for here - can be expected due to structural changes in the economy of poor countries.

- While aggregated figures are useful to generate discussion and support policy development, investments are made based on detailed analysis. Ultimately, detailed planning and costing at utility or project level is required[92]. Such studies include a number of considerations that are commonly excluded from macro analyses such as those reviewed in this article. For instance, detailed analysis is carried out with regard to expected profile of the demand at different time horizons[93]. In that

[91] More detailed considerations on affordability, however, go beyond the scope of this paper and we refer to the literature on the subject (e.g., Banerjee et al., 2008). It must nevertheless be noted that the estimates provided in this study are not to be interpreted as the amount of funds that will need to be raised internationally. Indeed, the consumers will pay part, possibly even all, of the cost.

[92] A number of tools have been developed and applied to assessing some of the related needs of developing countries including, notably, HOMER, WASP, and others (Howells et al. 2002).

[93] Howells et al. (2006) suggest a methodology to deal with such effects.

regard, our calculations do not take into account the possible impact on the load profile of adding a large number of a certain type of consumers (household). This would affect the load factor of power plants and therefore the price of electricity generation (depending on an enormous amount of variables including market structure, regulation, etc.). Importantly, the issues of power quality, system stability and ancillary services are not treated in our estimates or in most of the macro-literature we reviewed. These issues, central to the security of modern power systems, will likely add significantly to the cost of providing electricity. With regard to power planning, developing countries face a number of specific issues, notably, uncertainties related to future demographics and technical, economic and environmental constraints (Al-Shaalan 2009).

- What is sometimes referred to as soft costs are commonly not evaluated. Those include the costs associated with developing capacity of regional, national and sub-national institutions, a dimension that is crucial to scaling up energy access programmes (UNDP 2010a). It also consists of the support to private entities related to the operation of efficient energy systems for example. It is difficult to quantify those costs at global level[94], but various expenditures will be required to promote energy access beside those needed to purchase and run the energy systems.
- The existing infrastructure in numerous developing countries is crumbling. Foster and Briceno-Garmendia (2010) estimate a financing gap of USD 23 billion a year for Africa alone, three quarters of which is a shortfall in capital expenditure and the rest a shortfall of operation and maintenance spending. According to AGECC (2010), around USD 15 billion of grants would be needed to overcome infrastructure backlogs and deficiencies as well as meeting the suppressed demand[95] in least developed countries' productive sectors. This has not been considered in most global estimates.
- Because our estimates (and many of those surveyed) emphasize households, crucial dimensions of the economy are often left out. For instance, as societies develop, the need for heat and mechanical power is likely to increase, particularly to support the industrialization process. The same applies for energy requirements for transport which represents a significant share of the total energy consumption in industrialized countries. For context, IEA (2009a) reports that, globally, final energy consumption in transport and industry each is of the same order of magnitude as that of the residential sector.

5.5. Conclusion

We have critically reviewed estimates of the costs related to promoting energy access and provided a basis to compare the figures. Considering some of the gaps identified, we provided an estimate based on full levelised costs as a means of capturing dimensions absent from other analyses. While recognizing the coarse nature of our analysis, we find that the global cost of universal access to electricity ranges from USD 134 - 1410 billion for electrification and USD 78 - 128 billion for clean cooking. The total (electricity and cooking) reaches USD 212, 741, and 1538 billion for the low, medium and high scenarios, respectively. We note the sensitivity of the estimates to the underlying assumptions. Still, providing an order of magnitude assumption and bringing further transparency to methodological approaches can help support decision making at an international level and underpin political aspirations.

The total cost of reaching universal access to modern energy services might be significantly higher than indicated by the published studies. Our higher estimate is perhaps more realistic and is still possibly low, due to the methodological inadequacies discussed. Thus, we believe that for the purposes of political discourse, the total cost figure for full access to energy at over USD 100 billion per annum –

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94 UNDP (2010b) notes that capacity building costs represent half or more of the total cost of the some of their energy access programmes.

95 Suppressed energy demand is a situation whereby the desirable level of service cannot be reached. It is commonly due to a budget constraint or lack of adequate infrastructure.

and roughly 1.5 trillion in total to 2030 - is significantly larger than the most oft cited figures. It remains a fraction of total estimated investment costs in energy-supply infrastructure which amounts to USD 26 trillion for the period 2008-2030 (IEA 2009b, p. 104), and excludes recurrent costs.

While much remains to be done, and a significant share of the world's population still lacks access to modern energy, history has shown that progress in this regard can be both swift and wide-ranging. Providing that adequate incentives and conditions are in place, the investments required to promote energy access can unfold and bring about a number of associated developmental benefits. Past successes should serve as encouraging lessons to address the issue of energy access in the regions of the world where it remains a significant barrier to development.

Acknowledgments

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Annex 5-A: Assumptions on the share of generation systems

We assume that the electricity for rural electrification is provided for through the grid. In rural contexts, we assume the following share in the respective scenarios.

Table 5-6: Assumptions on the share of electricity generation systems

Assumption		Scenario		
		Low	Medium	High
Share of rural electrification through	grid	0.65	0.5	0.5
	mini-grid	0.34	0.4	0.4
	off-grid	0.01	0.1	0.1

Data source: own estimates based on IEA (2009a)

Annex 5-B: Assumptions on the levelised cost of electricity

Table 5-7: Assumptions on levelised costs of grid electricity per region for the low scenario

	Levelised cost [USc/kWh]				Share in electricity mix			
Energy source	Capital	O&M	Fuel	Total	Africa	Developing Asia	Latin America	Middle East
Coal	6.70	0.72	2.19	9.61	0.35	0.21	0.04	0.04
Oil	1.27	0.65	5.32	7.24	0.1	0.13	0.09	0.34
Gas	3.18	0.54	7.33	11.05	0.39	0.44	0.18	0.59
Nuclear	8.96	1.77	1.12	11.85	0.02	0.05	0.04	0
Hydro	4.56	0.82	0.00	5.38	0.12	0.13	0.61	0.02
Biomass & Waste	2.59	0.86	2.50	5.95	0	0.01	0.04	0
Others[xcvi]	40.39	1.21	0.00	41.60	0.02	0.03	0.00	0.01
Weighted average of total levelised cost [USc/kWh]					**10.1**	**10.4**	**7.0**	**9.9**

Data source: own estimates and calculations based on IEA (2009a), ESMAP (2007), IEA (2010a)

[xcvi] Cost assumptions based on solar PV.

Table 5-8: Assumptions on levelised costs of grid electricity per region for the medium scenario

	Levelised cost [USc/kWh]				Share in electricity mix			
Energy source	Capital	O&M	Fuel	Total	Africa	Developing Asia	Latin America	Middle East
Coal	6.70	0.72	2.19	9.61	0.11	0.07	0.09	0.01
Oil	1.27	0.65	5.32	7.24	0.03	0.06	0.02	0.23
Gas	3.18	0.54	7.33	11.05	0.56	0.51	0.21	0.66
Nuclear	8.96	1.77	1.12	11.85	0.02	0.05	0.03	0
Hydro	4.56	0.82	0.00	5.38	0.12	0.13	0.52	0.04
Biomass & Waste	2.59	0.86	2.50	5.95	0.03	0.07	0.04	0.02
Others	40.39	1.21	0.00	41.60	0.13	0.11	0.09	0.04
Weighted average of total levelised cost [USc/kWh]					**13.9**	**13.0**	**10.5**	**11.1**

Data source: own estimates and calculations based on IEA (2009a), ESMAP (2007), IEA (2010a)

Table 5-9: Assumptions on levelised costs of grid electricity per region for the high scenario

	Levelised cost [USc/kWh]				Share in electricity mix			
Energy source	Capital	O&M	Fuel	Total	Africa	Developing Asia	Latin America	Middle East
Coal	6.70	0.72	2.62	10.04	0.11	0.07	0.09	0.01
Oil	1.27	0.65	6.38	8.30	0.03	0.06	0.02	0.23
Gas	3.18	0.54	8.80	12.52	0.56	0.51	0.21	0.66
Nuclear	8.96	1.77	1.34	12.07	0.02	0.05	0.03	0
Hydro	4.56	0.82	0.00	5.38	0.12	0.13	0.52	0.04
Biomass & Waste	2.59	0.86	2.50	5.95	0.03	0.07	0.04	0.02
Others	40.39	1.21	0.00	41.60	0.13	0.11	0.09	0.04
Weighted average of total levelised cost [USc/kWh]					**14.8**	**13.9**	**10.8**	**12.3**

Data source: own estimates and calculations based on IEA (2009a), ESMAP (2007), IEA (2010a)

Table 5-10: Assumptions on levelised costs for mini-grid for the low scenario

Energy source	Levelised cost [USc/kWh]				Share in electricity mix
	Capital	O&M	Fuel	Total	
Diesel generator	0.98	5.00	26.00	31.98	0.6
PV-wind hybrid	22.02	8.47	0.00	30.49	0.4
Weighted average of total levelised cost [USc/kWh]					**31.4**

Data source: own estimates and calculations based on ESMAP (2007)

Table 5-11: Assumptions on levelised costs for mini-grid for the medium scenario

Energy source	Levelised cost [USc/kWh]				Share in electricity mix
	Capital	O&M	Fuel	Total	
Diesel generator	0.98	5.00	23.89	29.87	0.4
PV-wind hybrid	22.02	8.47	0.00	30.49	0.6
Weighted average of total levelised cost [USc/kWh]					**30.2**

Data source: own estimates and calculations based on ESMAP (2007)

Table 5-12: Assumptions on levelised costs for mini-grid for the high scenario

Energy source	Levelised cost [USc/kWh]				Share in electricity mix
	Capital	O&M	Fuel	Total	
Diesel generator	0.98	5.00	28.67	34.65	0.4
PV-wind hybrid	22.02	8.47	0.00	30.49	0.6
Weighted average of total levelised cost [USc/kWh]					**32.1**

Data source: own estimates and calculations based on ESMAP (2007)

Table 5-13: Assumptions on levelised costs for off grid for the low scenario

Energy source	Levelised cost [USc/kWh] Capital	O&M	Fuel	Total	Share in electricity mix
Diesel generator	5.01	5.00	92.60	102.61	0.2
PV-wind hybrid	31.40	10.38	0.00	41.78	0.5
PV[97]	45.59	10.50	0.00	56.09	0.3
Weighted average of total levelised cost [USc/kWh]					**58.2**

Data source: own estimates and calculations based on ESMAP (2007)

Table 5-14: Assumptions on levelised costs for off grid for the medium scenario

Energy source	Levelised cost [USc/kWh] Capital	O&M	Fuel	Total	Share in electricity mix
Diesel generator	5.01	5.00	85.80	95.81	0.5
PV-wind hybrid	31.40	10.38	0.00	41.78	0.2
PV	45.59	10.50	0.00	56.09	0.3
Weighted average of total levelised cost [USc/kWh]					**73.1**

Data source: own estimates and calculations based on ESMAP (2007)

Table 5-15: Assumptions on levelised costs for off grid for the high scenario

Energy source	Levelised cost [USc/kWh] Capital	O&M	Fuel	Total	Share in electricity mix
Diesel generator	5.01	5.00	102.96	112.97	0.5
PV-wind hybrid	31.40	10.38	0.00	41.78	0.2
PV	45.59	10.50	0.00	56.09	0.3
Weighted average of total levelised cost [USc/kWh]					**81.7**

Data source: own estimates and calculations based on ESMAP (2007)

[97] Based on 300 W PV plant.

Annex 5-C: Results of sensitivity the analysis

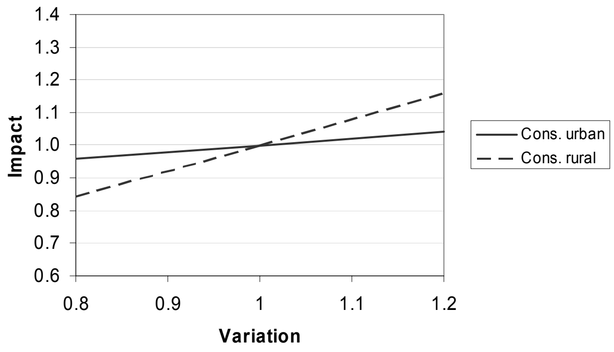

Figure 5-5: Impact on cost estimates of variation of rural and urban consumption

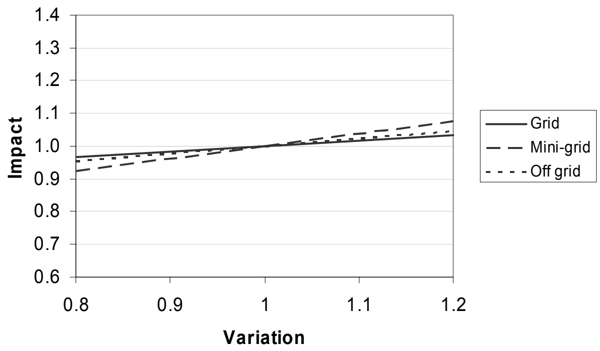

Figure 5-6: Impact on cost estimates of variation of levelised cost for grid, mini-grid and off grid systems

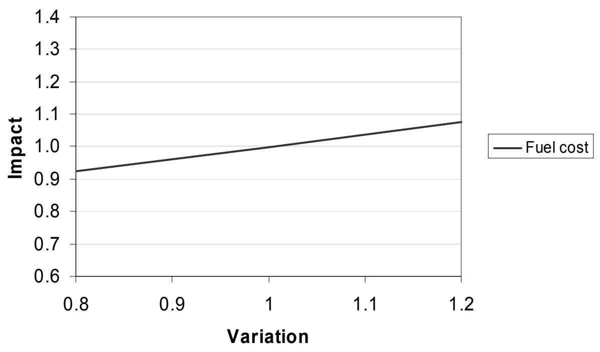

Figure 5-7: Impact on cost estimates of variation of fuel cost

6. Informing the Financing of Universal Energy Access: An Assessment of Current Flows

6.1. Introduction

Large investments will be required to address the massive expected energy demand growth in developing countries while also providing full access to energy services. To inform the design of policy tools to incentivise greater financial flows into expanding access, we focus on the macro financial flows in the energy sector (primarily infrastructure investment in the power and gas distribution sectors) in developing countries. We then briefly consider the relationship of these flows to the issue of energy poverty (see e.g. IEA 2010; Bazilian et al. 2010). We find that the financial flows related to the energy sector in developing countries are significant, but still inadequate to the task of delivering energy access to those who lack it. Ultimately, this research is presented to inform future more detailed analysis.

We build on the methodology devised to quantify the flows of investment in the climate change area (UNFCCC 2007). This methodology relies on national gross fixed capital formation, overseas development assistance, and foreign direct investment. We describe the methodology applied to estimate the financial flows in the energy sector in Section 6.2. In section 6.3, we present past trends. We then discuss some links with energy poverty in section 6.4. Section 6.5 outlines further work required to advance this research agenda.

6.2. Methodology

There is an extensive literature on international financial flows to developing countries, mostly going beyond the core of this analysis[98].

Data on current financial flows to the energy sector generally stem from either aggregated global or regional estimates, or scattered and un-processed datasets (Olbrisch et al. 2011). The principal obstacle in this analysis stems from data paucity, particularly in the case of developing and least developed countries (LDC). In particular, there is no comprehensive assessment of the current financial flows to address energy poverty. We utilise various sources to help address this analytical gap.

We focus on electricity production and gas distribution, which represents one of the dozen or so other sectors detailed in financial flow data sets[99]. Still, resource-rich developing countries are also the target of growing investments in the upstream energy sector of oil, coal and gas extraction and processing[100]. These investments are targeted mainly to the export sector and are not directly linked with the energy access infrastructure, thus they are not considered in this analysis[101].

We draw heavily on the precedent created to evaluate the investment and financial flows in the climate change space, notably the methodology applied in UNFCCC (2007). We complement the existing literature by:

[98] See e.g. Albuquerque 2003; Asiedu 2002; Bahmani-Oskooee 1986; Barnett 1993; Bird 1981; Claessens and Schmukler 2007; Fung 2009; Gelos, Sahay, and Sandleris 2011; Kasuga 2007; Kim 2000; Kinda 2010; Knight 1998; Laureti and Postiglione 2005; McGillivray 1989; Mishkin 2009; Mody and Murshid 2005; Munduch and Weinberg 1979; Noorbakhsh, Paloni, and Youssef 2001; Odedokun 1996; Rao 1997; Sadik and Bolbol 2001; Singh and Zammit 2000; Steel et al. 1997.

[99] The sub-sectors vary by dataset. They typically include, agriculture, hunting, forestry, fishing; mining and quarrying; manufacturing; electricity, gas and water supply; construction; transport, storage and communication; financial intermediation, real estate, renting and business activities; wholesale retail trade, repair of motor vehicles, motorcycles, etc, hotels and restaurants; public administration and defence, compulsory social security; education, health and social work, other community, social and personal services; and dwellings.

[100] There is a wide literature on the relation between extractive industries and poverty reduction with a particular relevance of the Extractive Industries Review process of the World Bank (Salim, 2003; World Bank, 2004; Pegg, 2006).

[101] On the specific topic of energy poverty in resource-rich countries, the WEO 2008 analyses ten Sub-Saharan oil exporting countries and concludes that the total additional cost of universal access to electricity and clean cooking stoves would be just 0.4% of the oil intake by the governments from 2006 to 2030 (IEA, 2008).

- Increasing the granularity in terms of geographical coverage and providing data at the national level for energy investments
- Refining existing estimates with additional information from various complementary sources
- Providing an update on the existing figures by using the most recent available datasets

6.2.1. Flows considered

Our estimates are based on data for a number of complementary flows: Gross Fixed Capital Formation[102] (GFCF), Foreign Direct Investments[103] (FDI), and Official Development Finance[104] (ODF). Table 6-1 presents a general overview of the financial flows considered in this analysis. GFCF represents the total investment flow. We include FDI and ODF to add richness to the analysis.[105]

Table 6-1: Overview of investment flow data[106]

Type of flow	Data source	Remark
Total		
GFCF	UNSTAT[107] and WDI[108]	data include water
International		
FDI	UNCTAD	data include water
ODF	AidData[109]	

National and international statistics offices do not generally record the yearly amount of domestic and international finance directed at the energy sector; available data thus present severe limitations. We apply basic statistical tools to estimate missing values, and employ several techniques to treat the available data. The section below provides a detailed overview of the data treatment for each flow. All data are converted into USD 2000 using GDP deflators and exchange rates[110]. We focus on the

[102] 'Gross fixed capital formation is measured by the total value of a producer's acquisitions, less disposals, of fixed assets during the accounting period plus certain specified expenditure on services that adds to the value of non-produced assets'. Source: (EU, IMF, OECD, UN, and WB 2009, 198).

[103] 'For associates and subsidiaries, FDI flows consist of the net sales of shares and loans (including non-cash acquisitions made against equipment, manufacturing rights, etc.) to the parent company plus the parent firm's share of the affiliate's reinvested earnings plus total net intra-company loans (short- and long-term) provided by the parent company. For branches, FDI flows consist of the increase in reinvested earnings plus the net increase in funds received from the foreign direct investor. FDI flows with a negative sign (reverse flows) indicate that at least one of the components in the above definition is negative and not offset by positive amounts of the remaining components'. Source: (UNCTAD n.d.).

[104] Official Development Finance data include: a) bilateral ODA; b) grants and concessional and non-concessional development lending by multilateral financial institutions; and c) those other official flows which are considered developmental but which have too low a grant element to qualify as ODA'. Source: (OECD 2010a, p. 274).

[105] International debt is another source of financing for governments and corporations beyond FDI and ODF. The Bank for International Settlements (BIS) records the debt issued in 40 main lending countries. Unfortunately, it is impossible to distinguish the economic sector in which borrowed money is spent based on the datasets available. International debt is therefore not included explicitly in this analysis.

[106] UNFCCC (2007) also includes international debt as a source of financing for the energy, gas and water sector and an estimation of the source of the investment (households, corporations, government) for the total of all sectors (tables IV-8 and III-2, respectively). These data are the results of an economic model built for the year 2000. We estimate GFCF as a time series to obtain insights on trends.

[107] UNSD (n.d.).

[108] WB (n.d.).

[109] Findley et al. (n.d.).

[110] Data source: (WB n.d.).

timeframe 2000-2009, and utilise data from project level databases (ODF and Private Participation in Infrastructure database[111] (PPI)) and data from National Accounts (GFCF and FDI). We recognize that investment decisions in the project level database may not reflect immediately in the national accounts, or may generate multi-year flows.

6.2.2. GFCF

GFCF data are aggregated for specific sectors and/or for the entire economy. Here we are interested in the *electricity, gas distribution and water supply*, for which data are available only for selected countries[112]. For the countries with incomplete time series for this sector, we use the average national share from the years for which data is available and compute the missing ones based on the total GFCF for years where it is not. Where sector-specific data are missing altogether, we use a weighted average share of GFCF for electricity, gas distribution and water supply over the total (3.8% and 8.1% for OECD and non-OECD, respectively) and compute it as a best approximation for the missing national data[113]. It is important to note that that GFCF data are based on national accounts' definitions of sectors, and therefore *electricity, gas distribution and water* are included in the same sector. Comprehensive datasets distinguishing the *water* component from *electricity and gas distribution* do not exist. We exclude the water component by subtracting it from the total based on the ratios[114] available in UNFCCC (2007), which are based on OECD data.

Various investments in coal, oil and gas production, processing and transportation facilities are spread across other sectors in the national accounts - mining and quarrying, industry, and transportation etc - which also include other facilities. Therefore, compiling data on investment in coal, oil, and gas supply from national accounts is challenging. Also, the extractive sectors are often export-oriented, and the link with national energy access is therefore weaker. Nonetheless, cumulative investment in coal, oil and gas is roughly equivalent to power sector investment (see e.g., IEA (2010c)). Finally, we have excluded a number of countries or sub-national entities[115] from the analysis for various reasons (e.g. statistical anomalies, lack of data).

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[111] Although the PPI database presents many project level details for the investments with private participation from international and domestic investors, the data do not precisely match the definition of Foreign Direct Investments, even if accounting only for the international part of the investments as we did. In particular, dis-investments, reinvested earnings (or repatriation of profits) and intra-company loans (positives or negatives) are not recorded and PPI, despite the obvious overlap with FDI data, cannot substitute it. The PPI data has been therefore used only to compare the share of water investments on the total energy plus water investment, a detail that is not included in the FDI statistics. The overall value of foreign investments recorded by the PPI for the period 2000-2008 for developing countries is 72% of the value recorded by FDI statistics. National shares may vary..

[112] Armenia, Australia, Austria, Azerbaijan, Belarus, Belgium, Botswana, Canada, Cyprus, Czech Republic, Denmark, Egypt, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, India, Iraq, Ireland, Israel, Italy, Jordan, Kenya, Republic of Korea, Kuwait, Kyrgyzstan, Latvia, Lithuania, Luxembourg, Macao SAR, Macedonia, Malta, Mauritius, Namibia, Netherlands, Netherlands Antilles, New Zealand, Niger, Norway, Pakistan, Poland, Portugal, Qatar, Slovakia, Slovenia, South Africa, Spain, Sudan, Sweden, Syrian Arab Republic, Trinidad and Tobago, Tunisia, Ukraine, United Arab Emirates, United States, and Yemen..

[113] In a few cases and for selected years (Andorra, Bermuda, Burundi, Channel Islands, Greenland, Guinea-Bissau, Haiti, Isle of Man, Kiribati, Liechtenstein, Maldives, Marshall Islands, Micronesia, Monaco, Palau, Samoa, San Marino, Solomon Island, Suriname, Tanzania, Timor-Leste, Netherland Antilles, West Bank and Gaza) where the total GFCF data is missing, we estimate it using a weighted share of GFCF for electricity, gas distribution and water over GDP (0.8% and 2.5% for OECD and non-OECD, respectively).

[114] Electricity: 77%; Gas distribution: 7%; and Water: 16%.

[115] Afghanistan, American Samoa, Cayman Islands, Democratic Republic of Korea, Faeroe Islands, Gibraltar, Guam, Mayotte, Myanmar, Northern Mariana Islands, Puerto Rico, Sao Tome and Principe, Somalia, Turks and Caicos Islands, Tuvalu, Sudan, and Virgin Islands (U.S.).

6.2.3. FDI

FDI data are available in aggregate and by sector, including for *electricity, gas distribution and water*. We only consider FDI inflows, as our interest lies in the investments in particular countries[116]. In general, the datasets are relatively 'patchy'. Rather than trying to extrapolate the figures based on bold assumptions to cover for the missing data, we focus our analysis on a subset of countries for which the data is available[117]. Thus we do not present an aggregated time-series, as we do for GFCF and ODF.

We use a complementary database, the Private Participation in Infrastructure Database[118] which collects data separately for projects in the *energy* and *water* sectors, to evaluate the proportion of investment in each of energy and water, which we then apply to isolate the water component. We find that at the global level, between 2000 and 2008, the investment in the water sector was approximately 10% of the total, although national shares can differ significantly. Unfortunately, UNCTAD does not differentiate between 'greenfield' and mergers and acquisitions flows; in other words, there is no means to distinguish between investments in new projects and financial transactions not leading to additional assets.

6.2.4. ODF

Official Development Finance data is available for the energy sector and its sub-components, including energy policy, renewable sources, non-renewable sources, and others. The source used, AidData (Findley et al. n.d.), contains all the data included in the Creditor Reporting System (CRS) database of the OECD and adds greater coverage of multilateral organizations and of non-OECD donors[119]. We include only projects related to the energy sector, following the methodology applied in OECD (2010b)[120], and exclude refinancing loans. It must be noted that ODF (or ODA) are commitments proclaimed by the donors, not actual flows.[121]

6.3. Financing energy: past trends

Financing for the energy sector is obviously contingent on trends in overall capital flows. The recent financial crisis affected developing countries in a number of ways. Notably, it hurt export revenues, caused remittances to decline, and ODA is likely to further suffer from the retrenchment of donor countries (UN 2011). While we focus on GFCF, Foreign Direct Investment, and Official Development Finance, other capital flows, in particular portfolio investments (debt and equity) and short and long-term private bank lending will provide additional finance to the energy sector.

[116] FDI is an important factor for growth in developing countries as it brings about skills, know-how and market access (UNIDO 2007).

[117] It is likely that some GFCF will occur every year in the electricity, gas distribution and water sector in a country, so estimating data for years with missing data using data for the other years appears as a reasonable assumption. However, when extrapolating figures for FDI, no inward FDI in the electricity, gas distribution and water sector is possible. Thus, estimating values for the years with zero inward FDI from data for the other years could then be incorrect and misleading.

[118] WB (n.d.)

[119] The average yearly sum of ODF commitments for the energy sector of LDCs recorded in the CRS database is 2.1% inferior of the same data selection in AidData.org database. If we consider all recipients, CRS present on average a yearly total 22.8% lower than AidData.

[120] ODF data is coded under CRS purpose codes. We have included in our analysis the following sub sectors and codes: 23010 Energy policy and administrative management; 23020 Power generation, non-renewable sources; 23050 Gas distribution; 23061 Oil-fired power plants; 23062 Gas-fired power plants; 23063 Coal-fired power plants; 23030 Power generation/renewable sources; 23040 Electrical transmission/distribution; 23065 Hydro-electric power plants; 23066 Geothermal energy; 23067 Solar energy; 23068 Wind owe; 23069 Ocean power; 23070 Biomass; 23064 Nuclear power plants; 23081 Energy education/training; 23082 Energy research.

[121] Disbursements are recorded only for a part (around half) of the records. For the projects for which both data exist, recorded disbursements are in average 30% inferior to commitments.

6.3.1. Gross Fixed Capital Formation

To provide a sense of scale, it is useful to consider energy-related investment in relation to global investment. The share of GFCF for energy represented 2.8% of the total in 2000, with the largest shares being wholesale retail trade (34%), manufacturing (17%), and construction (11%)[122].

Global GFCF for electricity and gas distribution has been rising steadily throughout the past decade, with the notable exception of 2009 (Table 6-2). At the regional level, the trends are similar, although not quite as clear-cut. GFCF for electricity and gas distribution in the OECD was stagnant or decreasing between 2000 and 2005, before picking up sharply. In the LDCs, GFCF in electricity and gas distribution has doubled in a decade, although the absolute value remains low.

Table 6-2: Overview of GFCF for electricity and gas distribution (USD billion) constant 2000 prices

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
OECD	179.1	183.0	175.1	174.3	168.3	173.3	191.8	211.6	222.7	172.2
Non-OECD[123]	53.5	58.3	60.1	71.2	77.0	84.8	98.1	123.4	153.4	144.5
LDC	1.3	1.4	1.6	1.6	1.7	1.9	2.0	2.3	2.5	2.6
Global	**232.6**	**241.3**	**235.2**	**245.5**	**245.3**	**258.1**	**289.9**	**335.0**	**376.1**	**316.6**

Note: The dataset for 2009 is incomplete; the sharp decrease is due to the economic crisis as well as to the fact that the dataset is incomplete at the date of writing

By means of comparison, IEA (2003) estimated the world investment in electricity and gas[124] in 2000 at USD 315 billion. UNFCCC (2007) estimated, based on UNCTAD and OECD data, the investment in electricity and gas distribution reaching USD 216 billion in 2000. Eberhard et al. (2011) also provide very useful analysis on investment in 24 countries of sub-Saharan Africa (SSA)[125].

Figure 6-1 shows the relative evolution in energy-related GFCF in selected[126] developing countries. The country datasets are normalized in 2000 to reveal the trends in the recent years. The curves for Namibia and, to a lesser extent, Armenia, urge for caution in interpreting the data, since the flows are subject to significant fluctuations, particularly if they are relatively small in absolute terms. Also, wide variations urge for caution in the interpretation of the datasets.

122 Data from UNFCCC (2007, p. 33).

123 This row includes the LDC figures.

124 Includes not only distribution, but also exploration and development, liquefied natural gas facilities, transmission pipelines, and underground storage facilities.

125 Table A7.1 of Eberard et al. (2011) estimate a yearly average capital expenditure of 2.2 billion (USD current, for the period 2001-2005, excluding Nigeria). As a comparison, for the same years and countries our estimation is 2.1 billion (USD 2000 constant) with the water sector, and 1.8 billion excluding it.

126 The countries highlighted in Figures 2 and 3 were selected to provide illustrative examples of various trends, they are not necessarily a representative sample.

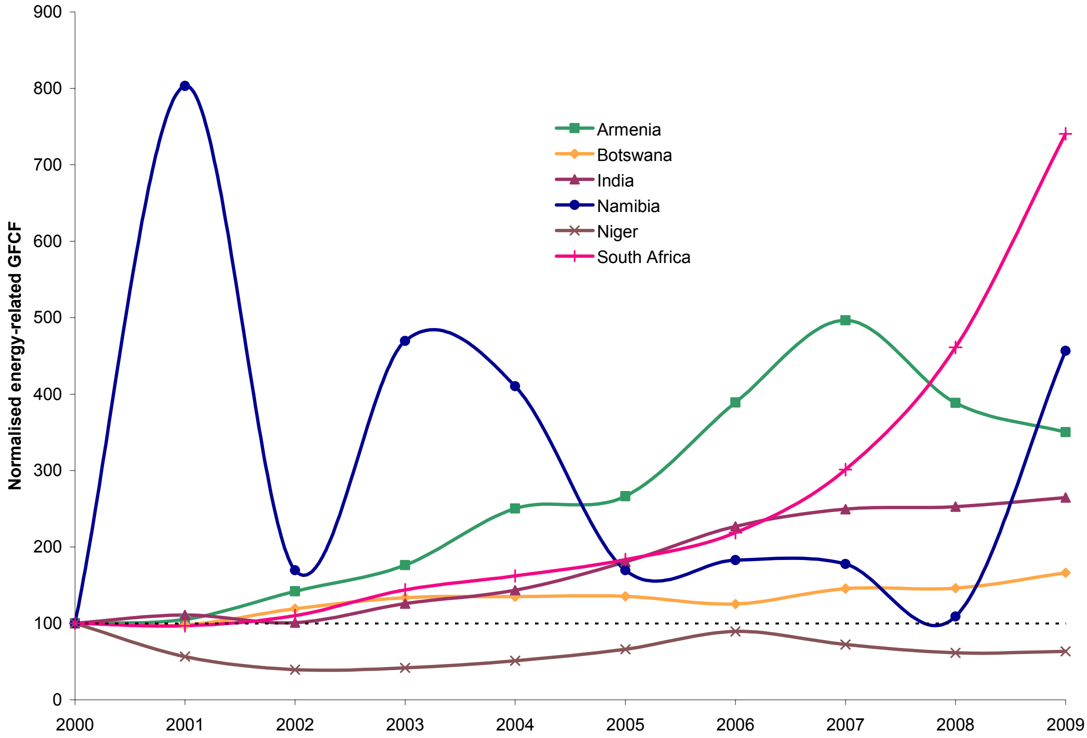

Figure 6-1: Relative trend in energy-related GFCF in selected developing countries, from constant 2000 USD

This notwithstanding, the analysis indicates a clear positive trend overall. That being noted, the rate of increase varies greatly between the countries (+60% and +160% for Botswana and India, respectively, over 10 years). Interestingly, the trend is in some cases negative, like in the instance of Niger. Noteworthy is also the case of South Africa, where energy-related GFCF increased exponentially in recent years. Incidentally, South Africa is one of the often-quoted success stories with regard to rapidly increasing the rate of access to electricity.

6.3.2. Foreign Direct Investment

Electricity, gas and water represents one of 15 sub-sectors in FDI data sets, including, *inter alia*, financial intermediation; paper and paper products; food beverage and tobacco. As noted, because of the difficulty in the robustness of the FDI data sets, we do not present a time-series of aggregated figures. However, as an example, we estimated the total 2000 flows to be 30 USD billion[127]. Foreign direct investment grew steadily for developed and developing economies over recent years until the global financial crisis of 2008. The effect of the crisis on FDI was evident in 2009, and was more pronounced in richer nations than for developing economies. About half of global FDI inflows now go to developing countries and transition economies (UNCTAD 2010). While the overall trends for FDI inflows in LDCs have been on the rise for the last decade (UNCTAD 2011), our analysis shows a downward tendency for energy-related[128] FDI inflows in those countries (see Figure 6-2 for several examples).

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[127] UNFCCC (2007) shows that figure as USD 27 billion.

[128] Based on available PPI data, the share of water is negligible for the 4 countries assessed.

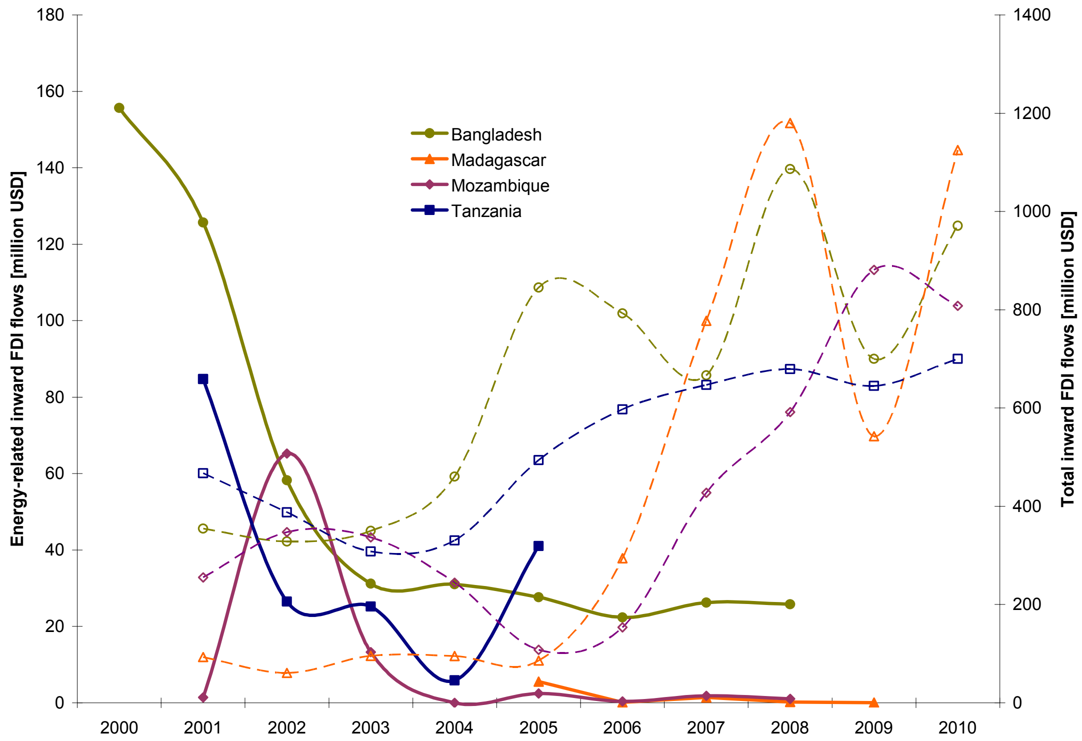

Figure 6-2: Energy-related (plain lines) and total (doted lines) inward FDI flows for selected LDC countries [constant 2000 USD]

Providing insights on trends by region over time is challenging given the data paucity; no clear pattern can be derived from an analysis across developing countries, as the energy-related FDI inflows vary widely between the years. Indeed, the flows have little 'inertia' and are strongly influenced by individual projects.

6.3.3. Official Development Finance

Aid for energy has been part of bilateral and multilateral aid effort for many years. Its level was relatively constant in the 1980's before decreasing deeply the following decade and reaching a minimum around the year 2000; it has been on the rise again since (see Figure 6-3). For the years 2000-2008, the categories that received the bulk of the energy related development finance were *Energy Policy*[129] (35%), followed by *Electrical Transmission* (26%), and *non-Renewable Energy* (17%).

[129] Includes: Energy sector policy, planning and programmes; aid to energy ministries; institution capacity building and advice; unspecified energy activities including energy conservation.

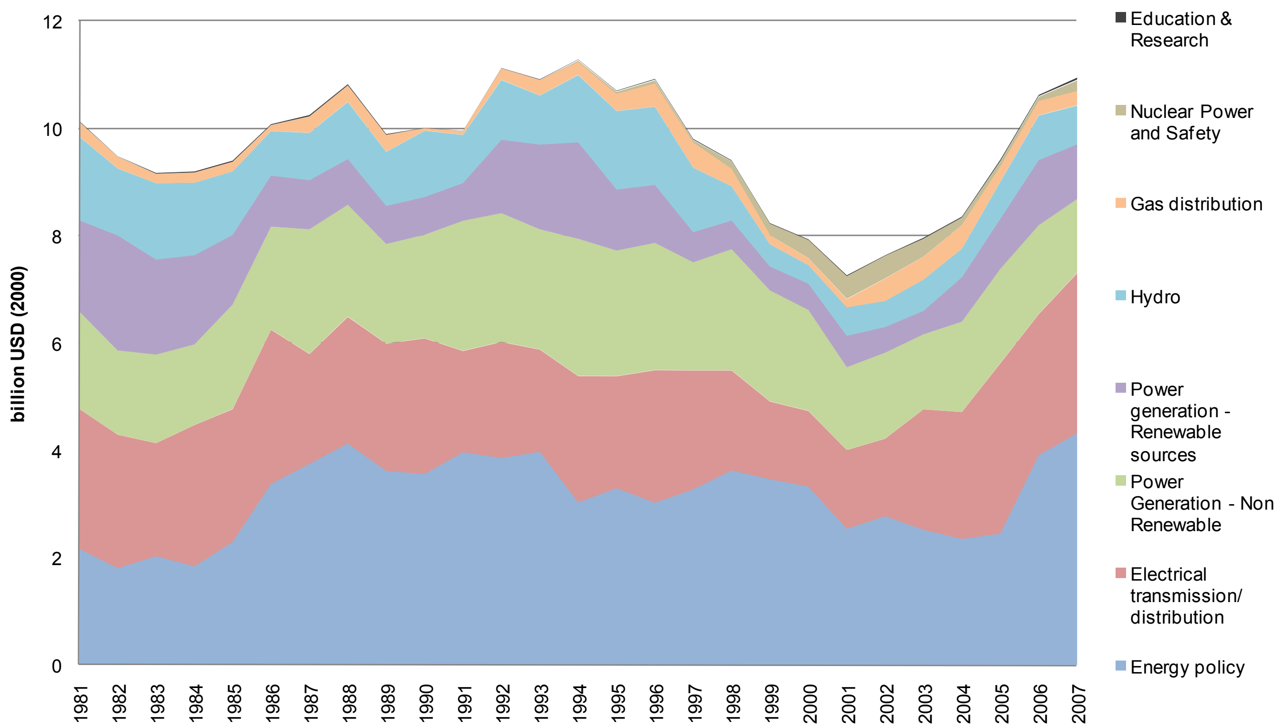

Figure 6-3: Development Finance for the Energy Sector by purpose; commitments, 1980-2008, using 3-year moving averages [constant 2000 USD]

There has been an almost continuous increase in electricity-related ODF in non-OECD countries during recent years. However, ODF to LDCs has varied widely over the years; it is nonetheless also on an increasing trend (Table 6-3).

Table 6-3: Overview of ODF for energy generation and supply [USD billion, constant 2000]

	2000	2001	2002	2003	2004	2005	2006	2007	2008
LDC	0.74	1.11	0.87	0.88	0.81	1.34	0.72	1.84	1.56
Other non-OECD	5.63	7.60	7.33	7.51	8.43	8.58	10.02	12.15	9.07
Global	**6.44**	**7.80**	**7.48**	**7.56**	**8.69**	**8.72**	**10.73**	**12.40**	**9.67**

6.3.4. Relationship between GFCF, FDI, and ODA/F

A number of scholars have looked into the relationship between ODA/F, FDI and GFCF. Obviously, the effect of FDI on capital formation largely depends on whether FDI is directed to 'greenfield' projects as opposed to cross-border Mergers and Acquisitions. Several authors have investigated the relation between FDIs and Official Development Assistance. UNCTAD notes that, especially in Least Developed Countries, FDIs tend to concentrate on the primary sector (mining) until a sufficient level of capability and infrastructure are built. In this context LDCs could leverage ODA for improving the conditions in their respective economies to attract more FDI and enhance their impact (UNCTAD 2010, p. 62).

While empirically examining FDI and GFCF for the economies in transition, Krkoska (2001) found that a 1% increase in FDI flows translated into 0.7% increase of GFCF in the recipient country. FDI represented an average 15% of the Gross Fixed Capital Formation (UNCTAD 2010), but its share can be higher for some developing countries (the average for African countries is above 20%). The relationship between ODA/F and gross fixed capital formation is much more ambiguous. First, ODA/F can finance a variety of activities that do not necessarily translate into any increase of fixed assets. Secondly, ODA/F statistics measure the declarations of the donor countries rather than actual flows (both for commitments and for disbursements). During the last couple of decades, FDI increased whilst ODA decreased in 13 LDCs (UNCTAD 2011).

While still below the level of ODA flows, FDI inflows for energy appear to have represented the major external private capital flows for LDCs in the past decade (UNCTAD 2011). Our analysis suggests that more than one third of the energy-related investment in LDCs stems from foreign sources, mainly from ODF. Although that share is high, the flow in absolute terms remains low (about $1/10^{th}$ with respect to other non-OECD countries, or 4% of the estimated world total) compared to other groups of countries.

6.4. Energy Poverty

Our interest in exploring macro financial flows is to set a context for finance for energy access. Energy poverty, the lack of access to modern, reliable and affordable energy services, affects billions of people. More than a fifth of the world's population does not benefit from access to electricity. It is well recognized that energy is a necessary ingredient for human development and the achievement of the Millennium Development Goals (Modi et al. 2005). Projections indicate that these issues will persist or worsen in the foreseeable future without dedicated action (IEA, UNDP and UNIDO 2010).

In 2010 the UN Secretary General's Advisory Group on Energy and Climate Change (AGECC) suggested two bold, yet achievable global objectives, one of which urges the international community to work towards achieving universal energy access by 2030 (AGECC 2010). While, at the regional, national, and local levels, significant efforts are underway to address the lack of energy access, the issue of 'unlocking' the requisite financing is paramount.

There does not appear to be a distinguishable relationship between investment in energy infrastructure and degree of energy poverty (see Figure 6-4)[130]. While GFCF appears to be positively correlated with the total number of people without access to electricity, that correlation disappears once one controls for total population.

[130] For Figure 6-4 and Figure 6-5, we selected the LDC countries for which we had the most confidence in the national data sets.

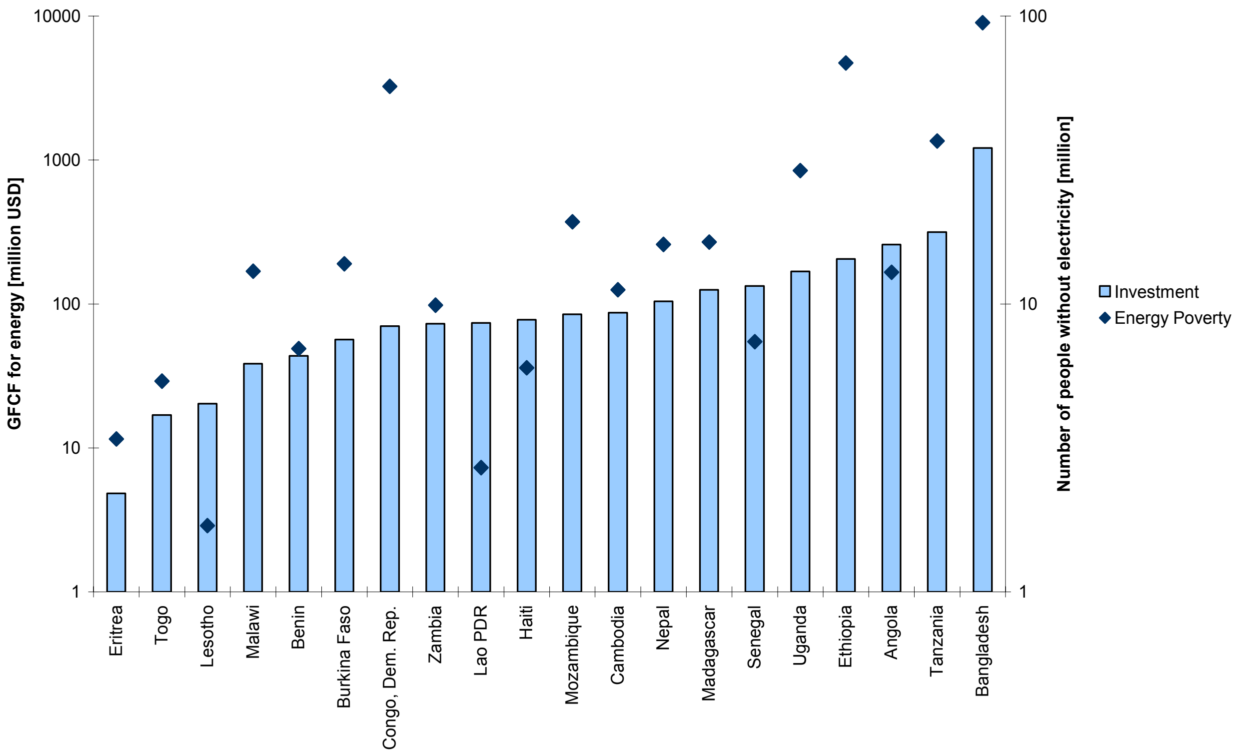

Figure 6-4: Magnitude of the financial flow in 2008 (primary ordinate axis) [USD 2000] compared to the number of people without access to electricity (2nd ordinate axis) sorted by investment (note: both axes in log scale) for selected LDCs.

Still, it is clear that existing country-specific investment flows in the energy sector are generally not sufficient to meet the needs of providing electricity services to those 1.4 billion people who currently lack any access– even if all investment was directed toward expanding access. In practice, of course, much of any investment will be directed toward increasing supplies (and quality) to those who already have some access.

Bazilian et al. (2010) estimate that the total cost of universal access to electricity for household uses and modern energy services for cooking could exceed USD 70 billion per year on average to 2030[131]. Focusing on countries with very low electrification rate, we compare (see Figure 6-5) energy-related GFCF in 2008 with the estimated annual average cost of universal household electrification in Least Developed Countries (LDCs) by 2030[132].

[131] This figure does not include the full investment required for all sectors of an economy as it focuses solely on household demand.

[132] Based on Bazilian et al. (2010); using the high scenario, and removing O&M and fuel costs from the original methodology.

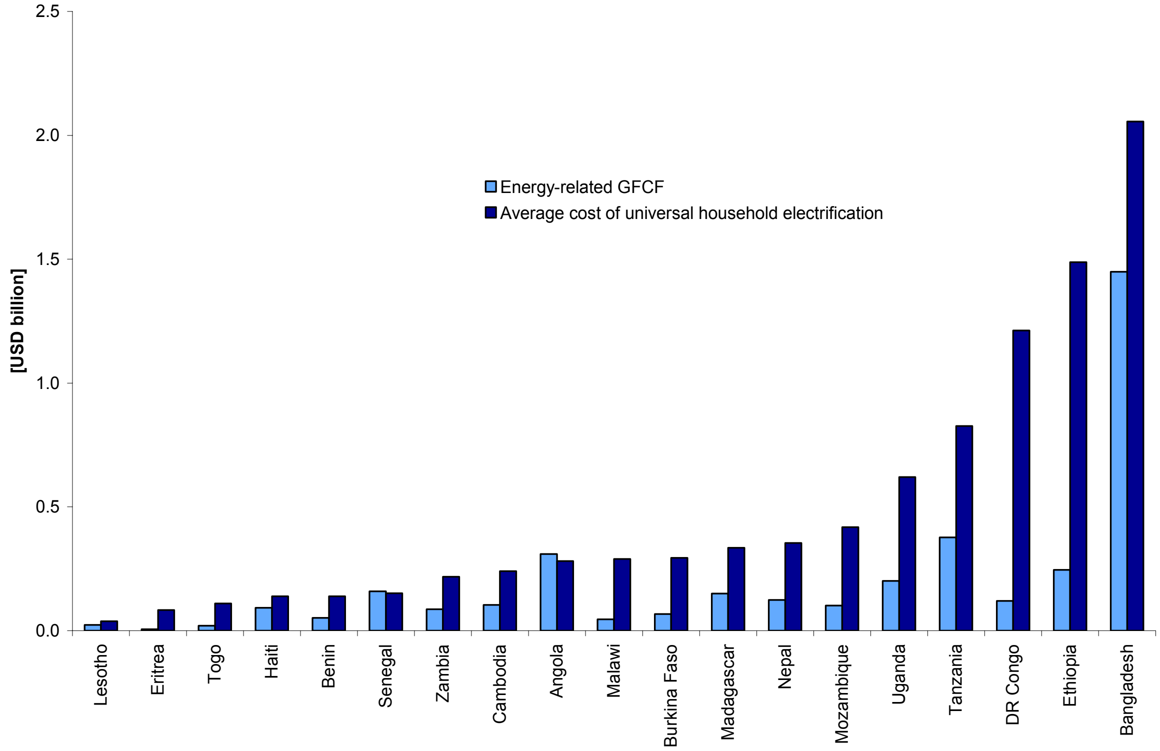

Figure 6-5: Comparing 2008 energy-related financial flows (GFCF) [USD 2000] with yearly average estimated investment needed for full household electrification in LDCs

Figure 6-5 indicates that even if all investment in energy capital was redirected to expanding access, it would be insufficient to bring about full household electrification by 2030 for most LDCs analyzed. For several countries (e.g. Democratic Republic of the Congo, Eritrea, Ethiopia, Malawi, Togo), the gap is huge (greater than fivefold). In aggregate, the total energy-related financial flow to LDCs compares poorly with estimated needs to reach universal access. Overall, and using the methodology for household energy from Bazilian et al. (2010)[133] we find an estimated need of a yearly average over the time period between 2011 and 2030 of USD 11.6 billion for LDCs compared to the total estimated flow of USD 2.5 billion in 2008, a gap that is similar to other recent estimates[134]. It must be noted that estimations of this gap would increase significantly if one were to include energy needs that go beyond household poverty alleviation (or that assume significantly higher per capita consumption over time).

Finally, considering data on international financial flows and comparing them with estimated requirements for universal energy access, implicitly suggests that significant funding for energy access will need to be sourced internationally. Traditionally, the bulk of investment for a country's power infrastructure has come mainly from domestic sources.

6.5. Further work

Efficient strategies to overcome energy poverty in the near future will require the careful consideration of the financial vehicles needed both in terms of the actual mechanisms and associated institutions. Both areas also require significant capacity development as a foundation. We briefly describe areas for possible further work in those areas.

- **Refining the analysis:** There is significant scope for refining our analysis. Notably, assessing dynamic aspects could provide valuable insights of policy relevance. Also, the paucity of the data

133 Based on Bazilian et al. (2010); Using the high scenario, and removing O&M and fuel costs from the original methodology to better equate to financial flows data sets.

134 Eberhard et al. (2011) provide a detailed analysis of the "funding gap".

represents a significant hindrance – especially in relation to providing insights about the relationship between macro financial flows and energy access issues. Therefore, improving the information base, both in terms of quantity and quality of the data, is crucial.

- **Delivery mechanisms:** This paper demonstrates that the gap between current and required flows is enormous in several cases. Securing political commitment and putting in place effective policy and regulatory frameworks are crucial elements to improve the investment climate for energy access. These include policies that are technology or sector specific, remove existing market distortions (e.g., fossil fuel subsidies), and work across sectors (education, health, water, agriculture, industry), as well as financing mechanisms to increase funding along the project spectrum (e.g. pre-feasibility studies, feasibility studies, seed capital, debt, equity, and insurance). There is a growing literature in this area (SELCO undated; UN-Energy/Africa undated; Practical Action undated; Williams & Ghanadan 2006; MacLean & Siegel 2007; Morris et al. 2007; Kammen & Kirubi 2008; Prasad 2008; Arc Finance 2009; Solano-Peralta et al. 2009; UNDP 2009; Moner-Girona 2009; Bloomberg New Energy Finance 2010; UNEP, SEFI & BNEF 2010; DB 2010; Laan, Beaton & Presta 2010).
- **Actors and institutional mapping:** Financial flows for the energy sector are of various types, origin and destination, and vary from multi-million dollar projects for large infrastructure to the few dollars necessary for an improved cookstove or for a solar panel. Significant experience has been gathered from decades of successful and less successful initiatives to address energy poverty at various levels. The lessons should be used and fed into new strategies. The literature reports on some of those issues (Morris & Kirubi 2009; Casillas & Kammen 2010; Howells et al. 2010).
- **Sources of financing:** The additional financial resources required to achieve goals like that of universal energy access will stem from various sources. A useful area of further investigation would be to improve the understanding related to the share of those 'catalytic' investments that is expected to be provided by the public sector. This is the kind of information that government policy can be built upon.

6.6. Conclusion

We have provided an updated and refined estimate of macro financial flows to the energy (power) sector in developing countries using several data sets and analytical techniques. The results are primarily 'high-level' aggregates which provide a sense of scale. Of the 2008 total GFCF, LDCs comprise approximately 0.7%. We then compared those flows to national investment needs and to electrification rates. Current flows are, as a minimum, a factor of five less than that required for universal household access to electricity. Data paucity remains a significant obstacle to further, more refined analysis. This small contribution is presented to improve understanding of the 'decision space' of energy poverty and to help inform policy design.

Acknowledgments

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Annex 6-A: Energy-related[135] GFCF by country [constant 2000 USD, million]

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Albania	61.7	73.6	67.3	68.1	73.3	76.6	85.4	106.3	125.2	115.9
Algeria	767.1	862.5	974.2	1023.8	1080.4	1052.1	1101.3	1285.7	1335.1	1705.1
Andorra	23.2	26.0	27.5	29.4	31.3	33.1	35.4	35.9	37.1	
Angola	93.0	85.4	91.7	95.5	76.4	81.6	135.7	201.8	258.5	265.0
Antigua and Barbuda	21.6	22.9	24.2	25.7	26.6	32.7	46.3	49.1	54.1	47.4
Argentina	3116.0	2608.3	1960.5	2700.5	3728.1	4556.3	5379.3	6056.7	6221.5	5637.1
Armenia	31.7	33.3	44.9	55.9	79.3	84.3	123.2	157.2	123.0	110.9
Aruba	31.3	29.1	32.5	35.3	442.4	519.8	551.8	545.5	542.4	
Australia	3544.1	4060.6	3948.7	4283.3	4761.7	5526.2	6727.3	8243.4	5979.9	5968.6
Austria	1057.8	997.7	886.8	925.0	997.0	1232.4	1349.8	1222.7	1313.5	1108.1
Azerbaijan	110.9	90.8	137.5	150.3	48.8	186.8	407.2	366.9	373.5	309.0
Bahamas, The	126.5	114.0	106.8	105.1	99.6	127.5	154.0	155.9		
Bahrain	72.9	75.3	111.5	127.1	163.0	166.7	199.9	221.1	284.0	2612.6
Bangladesh	734.2	775.1	811.4	863.6	941.9	1019.0	1092.0	1153.4	1212.0	1291.7
Barbados	31.8	34.8	35.1	449.3	523.5	537.2	480.1	500.4	510.5	480.8
Belarus	158.7	141.5	182.5	223.2	276.8	281.0	321.8	356.0	464.2	500.0
Belgium	1110.5	545.3	1070.9	816.6	1183.4	856.4	1302.7	1541.4	1705.2	1208.5
Belize	16.1	14.9	14.0	12.9	12.6	13.6	14.2	15.0	20.5	
Benin	28.9	30.8	30.4	31.4	31.5	34.9	35.0	43.0	43.7	54.8
Bermuda	44.6	73.3	30.0	30.0	36.6	37.2	35.4	94.8	95.5	
Bhutan	14.6	16.7	20.0	21.1	23.4	23.1	21.3	21.2	26.6	32.6
Bolivia	101.7	80.5	92.7	77.1	74.1	85.8	91.0	117.1	132.8	131.2
Bosnia and Herzegovina	76.6	74.3	76.1	80.3	78.5	103.0	124.6	159.6	160.0	107.4
Botswana	43.9	43.0	52.4	58.7	59.3	59.6	55.1	63.9	64.1	73.0
Brazil	7333.6	7532.2	7439.5	7016.0	7814.2	7981.9	8554.1	9632.5	10839.2	9697.2
Brunei Darussalam	52.7	61.1	91.9	66.9	60.2	51.1	49.2	61.3	1239.7	
Bulgaria	137.9	165.5	173.6	191.6	217.1	302.1	341.4	382.2	462.9	317.9
Burkina Faso	33.1	27.6	33.9	37.2	43.0	46.1	52.0	54.2	56.7	85.3
Burundi	2.9	3.0	3.1	5.4	6.9	5.6	9.2	17.6	18.4	19.1
Cambodia	45.3	42.4	54.3	57.8	62.6	73.0	82.9	93.3	86.9	102.9
Cameroon	109.2	144.4	147.0	139.4	146.0	144.7	140.8	149.3	161.7	89.7
Canada	4161.2	4804.8	4684.8	4798.1	5233.5	5653.3	6105.6	6330.3	6388.2	5880.6
Cape Verde	7.1	6.8	8.2	7.8	15.4	17.2	20.6	24.2	28.4	32.5
Central African Republic	6.2	5.4	5.8	3.7	3.7	5.5	5.9	5.9	7.9	7.4
Chad	19.6	38.3	67.8	63.3	39.6	34.1	27.1	34.9	48.9	69.6
Channel Islands	132.0	130.0	127.9	123.8	124.0	125.8	131.9	139.7		
Chile	490.4	531.3	532.8	523.3	531.2	615.2	591.2	652.4	784.7	696.1
China	27681.9	30259.1	34766.6	41537.3	47296.6	51878.4	59225.6	65050.7	74356.6	90735.9
Colombia	971.9	1070.6	1173.7	1307.4	1413.2	1538.5	1766.9	1956.9	1891.3	1903.2

[135] Electricity and gas distribution.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Comoros	1.4	1.4	1.6	1.6	1.4	1.5	1.6	2.2	2.6	3.1
Congo, Dem. Rep.	10.1	14.9	26.4	38.2	42.6	50.4	48.6	77.4	100.3	128.9
Congo, Rep.	45.6	59.4	53.4	60.8	54.1	58.3	68.9	78.9	70.3	84.5
Costa Rica	192.0	199.7	211.8	229.0	231.9	247.2	285.7	337.1	517.1	417.4
Cote d'Ivoire	78.9	69.8	75.6	66.5	68.6	68.7	66.3	62.7	74.9	87.0
Croatia	271.9	290.6	334.8	414.1	426.2	443.2	493.0	522.0	561.5	474.1
Cuba	245.8	247.7	221.1	199.8	226.7	301.4	379.8	388.8	402.8	
Cyprus	44.2	38.1	33.2	55.2	66.0	97.0	107.9	120.3	132.2	
Czech Republic	996.9	942.8	772.7	849.2	684.9	746.1	835.7	882.4	919.3	850.8
Denmark	833.0	674.4	873.5	907.4	805.1	714.1	997.9	1102.2	1161.7	800.0
Djibouti	3.3	3.0	3.9	5.8	9.0	8.2	13.4	17.8	15.2	16.0
Dominica	5.2	4.2	3.5	4.3	5.0	5.5	5.9	6.1	6.9	6.4
Dominican Republic	332.3	314.1	339.3	257.9	260.9	316.2	390.7	435.9	443.6	371.0
Ecuador	221.2	243.2	276.1	262.0	286.2	309.0	331.3	335.8	387.7	461.5
Egypt, Arab Rep.	259.1	611.1	661.9	3577.1	1166.4	1061.4	1197.1	1066.2	1416.6	1624.8
El Salvador	150.6	148.6	153.6	158.0	151.0	152.0	167.1	172.7	165.6	135.3
Equatorial Guinea	52.1	98.9	53.2	77.8	104.5	106.7	90.0	116.2	109.4	134.4
Eritrea	10.2	17.1	14.4	13.2	10.6	9.0	6.1	5.2	4.8	
Estonia	94.1	88.7	164.4	184.8	150.6	178.7	189.5	154.2	185.3	116.1
Ethiopia	112.3	128.7	145.7	130.1	172.3	174.0	203.2	219.2	205.5	252.4
Fiji	17.5	17.8	23.0	26.0	23.6	27.0	26.5	23.2	27.1	12.3
Finland	655.1	705.9	695.5	656.2	899.3	842.2	863.5	916.8	1231.0	835.1
France	5787.5	5033.4	5048.9	4740.9	5130.8	4254.4	5942.0	6702.6	6716.8	6043.8
French Polynesia	35.8	461.6	536.6	516.5	530.9	522.2				
Gabon	75.2	90.1	85.7	85.8	88.5	79.7	97.9	103.4	99.6	115.0
Gambia, The	5.0	5.2	6.2	6.0	8.3	15.5	18.0	17.2	12.8	13.3
Georgia	52.7	59.1	56.0	67.8	73.9	82.8	82.4	93.2	79.7	51.4
Germany	9865.6	9367.7	9078.8	8438.4	8740.6	8858.8	9765.1	9937.5	10169.2	8864.9
Ghana	77.8	95.1	68.8	88.4	115.5	125.0	159.0	160.6	191.1	176.5
Greece	829.6	751.1	536.7	500.6	502.5	506.6	502.1	478.7	491.8	513.9
Greenland	21.9	22.2	22.0	21.9	22.5	22.9	23.9	25.2	25.3	
Grenada	12.1	9.5	8.7	12.0	11.7	16.3	12.0	10.7	9.4	7.2
Guatemala	210.6	244.7	268.0	265.7	269.3	277.4	321.3	333.4	316.7	271.1
Guinea	39.7	32.9	31.1	47.0	47.9	46.4	42.6	36.2	42.3	43.3
Guinea-Bissau	1.6	2.2	1.3	4.1	4.2	4.3	4.3	4.5	4.6	
Guyana	11.5	10.9	10.5	10.4	12.0	16.2	23.8	22.1	22.7	
Haiti	75.1	74.3	74.1	74.4	71.8	73.1	74.7	77.2	77.9	80.1
Honduras	124.0	118.3	110.3	122.9	154.2	150.5	176.0	216.6	230.8	154.3
Hong Kong SAR, China	3018.9	2950.0	2624.4	2557.5	2787.6	2932.7	3282.2	3215.1	3213.4	
Hungary	591.0	483.8	505.6	544.6	515.4	469.7	482.0	407.0	422.7	464.2
Iceland	132.9	160.7	150.4	257.0	310.2	434.5	416.5	369.7	318.9	169.7
India	7516.7	8334.4	7593.0	9467.8	10779.8	13562.1	17047.2	18757.5	18997.1	19906.1
Indonesia	2218.1	2278.2	2351.3	2473.4	2989.8	3327.7	3583.6	3939.9	4634.4	5437.0
Iran, Islamic Rep.	1813.1	1989.8	2166.6	2352.8	2458.6	2429.6	2512.4	2647.5	3182.7	3240.0

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Iraq	128.0	238.4	142.4	465.3	585.8	673.3	1063.5	2239.9	798.9	832.4
Ireland	819.0	930.7	1224.6	1218.7	1282.5	1257.8	1234.3	1062.1	1056.5	772.0
Isle of Man	10.3	10.8	11.4	12.2	12.8	13.6	14.6	15.7		
Israel	829.5	849.5	909.9	1190.2	1112.8	978.9	848.0	737.9	876.9	1070.4
Italy	6682.9	7078.5	7625.6	8320.1	7366.2	7583.5	8136.9	8527.9	7856.4	6843.5
Jamaica	142.4	160.7	170.3	171.6	175.9	180.1	192.9	185.0	159.3	139.6
Japan	36967.1	36295.6	34322.4	34101.6	34905.9	36503.2	37332.7	37537.3	37695.6	31648.8
Jordan	152.6	171.5	140.2	187.1	183.2	231.2	111.7	106.5	257.6	168.1
Kazakhstan	214.5	333.6	370.8	388.7	463.8	567.2	678.1	734.0	678.0	785.3
Kenya	5.0	4.7	4.6	4.6	138.2	168.3	182.6	199.3	203.3	206.0
Kiribati	1.4	1.4	1.4	1.5	1.5	1.6	1.6	1.6	1.6	1.7
Korea, Rep.	6978.9	7224.3	6941.9	6722.6	6193.2	6638.9	7030.0	7760.0	7738.4	8393.8
Kosovo	37.9	48.1	47.8	50.4	34.0	35.0	47.1	50.1	57.8	58.6
Kuwait	962.7	1069.3	1158.1	1286.8	1215.4	966.3	887.3	1126.2	17920.9	
Kyrgyz Republic	6.2	12.6	12.7	29.7	28.1	23.8	21.2	29.5	29.8	31.5
Lao PDR	33.2	33.7	34.9	39.1	47.4	54.9	53.0	71.2	74.0	64.2
Latvia	123.7	137.9	137.1	171.8	234.5	243.0	202.9	222.6	205.3	149.3
Lebanon	245.7	252.4	243.6	256.6	292.1	312.3	325.1	408.1	493.8	526.3
Lesotho	21.4	20.0	18.2	18.7	15.3	14.9	15.2	16.8	20.3	21.3
Liberia	0.0	1.9	1.9	2.6	3.8	4.9	0.0	0.2	0.2	12.0
Libya	301.5	275.6	289.6	239.3	354.3	444.5	616.1	788.8	913.7	1012.1
Liechtenstein	50.9	50.5	50.0	49.1	50.6	53.0	57.6	59.5	60.6	
Lithuania	156.6	177.7	191.6	186.9	204.3	210.1	321.7	322.8	291.5	249.6
Luxembourg	131.1	132.7	167.4	212.3	129.4	133.9	155.6	115.5	128.1	136.2
Macao SAR, China	41.8	61.2	56.7	47.2	58.3	59.6	35.3	29.2	122.5	
Macedonia, FYR	45.2	38.5	39.2	49.4	53.5	34.9	58.6	49.5	112.3	70.8
Madagascar	39.5	51.5	34.7	47.7	65.7	65.2	78.1	90.7	125.4	121.3
Malawi	14.5	15.5	14.5	18.5	21.9	26.5	27.7	35.0	38.5	34.2
Malaysia	1606.2	1603.7	1579.9	1595.2	1592.5	1642.3	1758.4	1946.2	1843.2	1876.9
Maldives	11.1	12.3	12.9	14.9	21.1	30.7	40.4	22.0	23.3	22.6
Mali	40.3	57.0	35.6	49.9	44.1	50.5	53.7	54.8	47.1	52.0
Malta	47.6	39.8	35.2	59.0	40.1	19.5	20.4	20.9		
Marshall Islands	2.2	2.3	2.4	2.4	2.5	2.5	2.6	2.7	2.6	2.6
Mauritania	14.2	16.6	16.0	20.8	39.2	40.0	23.2	26.3	31.9	31.5
Mauritius	61.2	47.5	40.8	48.1	44.7	66.1	73.0	44.2	16.5	34.5
Mexico	3906.9	3651.2	3543.0	3534.2	3824.8	4006.9	4393.2	4639.6	4826.0	4495.5
Micronesia, Fed. Sts.	4.6	4.7	4.7	4.8	4.6	4.8	4.7	4.7	4.6	3.9
Moldova	13.5	12.5	16.3	19.7	24.2	30.2	36.5	45.2	48.6	34.5
Monaco	54.3	55.5	56.0	56.6	58.0	59.1	62.1	71.2	78.3	
Mongolia	18.5	16.5	19.0	27.3	28.9	30.7	35.4	44.7	47.0	63.4
Montenegro	11.2	11.8	10.0	9.4	12.6	13.8	18.2	29.8	37.6	24.8
Morocco	651.2	669.8	702.4	743.7	815.6	879.8	969.1	1105.4	1233.2	1211.0
Mozambique	89.0	64.3	104.9	82.7	74.7	81.2	83.3	81.7	84.8	120.4
Namibia	16.4	131.9	27.8	77.1	67.4	27.8	30.0	29.2	17.9	75.0

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Nepal	71.9	74.0	76.4	80.8	86.4	87.3	94.1	95.7	104.4	110.0
Netherlands	1242.5	1023.0	938.0	1037.6	1139.9	1086.0	1425.3	1611.6	1351.5	1203.7
Netherlands Antilles	50.3	23.4	78.8	130.3	108.3	158.4	144.5			
New Caledonia	50.5	642.5	722.2	909.3	850.3	997.8	1325.5			
New Zealand	326.9	350.9	387.7	463.7	470.4	578.5	550.3	526.3	491.5	436.3
Nicaragua	70.8	74.6	68.1	70.3	79.3	88.3	90.7	100.1	107.2	90.8
Niger	45.7	25.9	18.0	19.2	23.3	30.2	40.8	33.0	28.0	28.9
Nigeria	220.4	223.7	228.5	356.1	294.0	228.8	367.9	434.8	415.4	1564.4
Norway	518.2	492.7	680.4	780.4	861.7	857.2	867.6	989.9	1043.9	959.4
Oman	160.6	182.8	278.8	332.3	393.4	370.2	408.6	551.1	604.1	
Pakistan	1089.1	1013.5	831.7	806.2	328.5	486.4	767.4	750.6	780.4	524.1
Palau	2.5	2.5	2.4	2.4	2.5	2.6	2.7	2.8	2.7	2.7
Panama	166.7	120.2	109.7	143.9	150.3	163.4	192.9	260.5	289.6	319.4
Papua New Guinea	48.7	50.4	46.2	44.1	45.2	46.8	48.0	51.2	56.4	58.8
Paraguay	84.0	84.9	85.0	96.2	98.6	104.9	108.0	105.2	112.9	88.8
Peru	729.1	671.4	666.4	703.0	741.8	812.2	922.2	1124.2	1487.1	1420.8
Philippines	1088.6	938.0	962.1	965.3	981.5	921.0	946.4	1062.4	1101.2	1114.7
Poland	1908.2	1983.5	1739.6	1777.0	1707.9	1686.3	1892.3	2317.7	2600.4	2519.8
Portugal	1005.8	792.6	753.2	870.2	925.5	1302.3	1408.3	1031.5	1024.8	867.7
Qatar	125.8	76.5	134.6	119.2	448.7	530.3	357.7	15904.2	20505.7	19225.6
Romania	474.3	547.7	594.0	627.7	687.5	762.3	840.9	1090.2	1289.4	1150.3
Russian Federation	2965.5	3490.6	3466.1	3816.4	4088.3	4203.0	4723.1	5788.5	6452.2	5756.9
Rwanda	21.5	24.3	25.0	26.4	30.4	34.6	35.0	38.9	49.7	49.0
Samoa	4.7	5.1	5.3	5.6	5.8	6.1	6.2	6.3	6.7	6.3
San Marino	22.5	28.9	33.4	33.0	32.3	32.7	32.7	20.1	20.5	
Saudi Arabia	2226.8	2357.2	2326.7	2545.4	2424.6	2542.2	2766.2	3284.2	3308.7	4196.0
Senegal	71.1	75.5	83.0	75.5	85.7	118.4	115.4	132.5	133.6	122.9
Serbia	52.4	46.4	56.0	77.1	96.2	100.5	117.1	142.8	145.9	146.6
Seychelles	10.5	16.5	10.5	4.0	4.8	10.0	11.5	14.2	12.1	10.7
Sierra Leone	3.0	3.4	6.6	9.8	8.0	13.9	13.3	12.3	14.5	15.5
Singapore	1920.4	1829.7	1617.9	1574.3	1677.6	1684.9	1884.7	2192.6	2638.5	2726.2
Slovak Republic	823.2	692.0	661.0	481.8	541.8	560.2	908.6	2168.8	1072.3	943.9
Slovenia	256.6	205.8	201.8	201.8	208.2	248.9	321.0	367.0	347.3	265.5
Solomon Islands	1.8	1.7	1.3	2.6	3.0	3.9	4.4	11.1	11.9	11.7
South Africa	652.3	632.3	719.2	938.2	1058.1	1195.8	1427.3	1963.9	3007.7	4830.1
Spain	3579.7	3583.5	4128.9	3964.0	5041.8	5249.3	6230.0	5600.9	5362.0	4340.4
Sri Lanka	310.0	239.5	227.2	240.3	286.2	314.0	359.7	381.8	413.8	403.0
St. Kitts and Nevis	11.1	12.2	11.8	10.4	10.8	11.0	10.4	12.0	11.9	10.7
St. Lucia	12.3	11.3	10.2	9.8	10.6	12.5	16.3	15.5	15.0	13.1
St. Vincent and the Grenadines	6.2	6.8	7.0	8.3	8.5	8.6	10.5	11.6	11.6	11.1
Suriname	7.5	18.3	14.6	16.0	16.9	19.8	25.0	26.3	27.7	
Swaziland	17.5	22.7	20.9	20.5	17.9	17.4	16.4	16.8	18.8	21.0
Sweden	1734.7	1641.9	1659.0	1845.6	1994.0	2584.0	3222.8	3549.5	3811.4	2435.9
Switzerland	1781.3	1740.8	1703.2	1635.9	1701.3	1776.4	1850.5	1940.0	1949.3	1929.0

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Syrian Arab Republic	352.7	332.9	375.3	483.0	561.7	602.4	480.8	417.2	439.6	537.6
Tajikistan	4.3	5.8	4.4	6.2	8.9	12.5	12.4	23.1	23.2	20.1
Tanzania	107.2	109.8	132.9	136.8	143.8	136.3	148.9	283.3	315.4	332.8
Thailand	1825.5	1953.7	2039.3	2305.7	2640.2	3079.7	3145.8	3101.3	3303.9	2873.5
Timor-Leste	4.7	9.8	8.0	6.8	6.1	6.4	6.1	6.5	7.4	7.5
Togo	16.0	19.2	17.6	20.1	21.0	22.3	17.5	15.4	16.9	20.1
Tonga	2.7	3.2	4.0	3.5	3.3	3.0	2.6	2.7	3.5	3.7
Trinidad and Tobago	124.6	26.8	57.4	43.6	21.2	32.8	40.0	48.7	42.9	67.0
Tunisia	280.0	283.4	208.7	216.1	278.3	244.0	792.2	1096.8	214.6	519.8
Turkey	1710.1	1260.6	1403.8	1503.4	1966.0	2203.4	2496.3	2559.7	2347.3	1893.1
Turkmenistan	68.3	75.1	75.6	81.6	86.8	97.5	92.4	96.3	79.1	72.2
Uganda	80.7	83.8	93.5	103.1	106.4	125.9	131.5	148.7	168.2	190.0
Ukraine	265.4	290.3	386.5	418.1	489.9	370.6	412.8	434.2	592.7	352.6
United Arab Emirates	1020.0	1276.1	1279.3	1243.6	1413.0	1352.2	1534.2	1516.7	1688.6	1782.5
United Kingdom	7957.4	8006.8	8162.7	8189.8	8559.2	8779.9	9253.4	9876.4	9239.1	7746.4
United States	58994.5	65380.5	58806.2	57708.9	47417.7	47403.1	54718.7	68017.4	82349.5	49862.2
Uruguay	221.3	203.9	164.1	169.9	218.1	267.8	313.8	336.6	398.4	386.9
Uzbekistan	223.5	271.1	223.4	226.6	266.9	266.5	234.2	297.7	392.8	438.1
Vanuatu	3.5	3.3	3.1	3.0	3.5	3.8	4.5	5.2	7.7	7.7
Venezuela, RB	1667.1	1972.4	1638.9	1066.7	1495.7	1826.5	2150.3	2546.9	2240.8	2395.3
Vietnam	583.5	657.7	752.4	865.0	929.6	996.4	1094.2	1361.7	1314.1	1386.1
West Bank and Gaza	91.0	53.1	55.5	60.6	60.1	65.8	982.7	778.3		
Yemen, Rep.	166.6	202.4	314.0	278.1	269.7	282.5	295.3	408.5	371.6	341.0
Zambia	35.1	40.6	48.6	60.1	60.7	62.3	66.4	74.5	73.0	72.6
Zimbabwe	0.1	0.1	0.0	0.1	0.1	0.1	120.1	0.0		

7. On the contribution of labelled Certified Emission Reductions to sustainable development: A multi-criteria evaluation of CDM projects

7.1. Introduction

The Kyoto Protocol creates a legally binding set of obligations for industrialised countries and obliges those countries to reduce their emissions of greenhouse gases to an average of 5 per cent below their 1990 levels over the commitment period 2008-2012 (UNFCCC 1997, p. 3). Three flexible mechanisms, Emission Trading, the Clean Development Mechanism (CDM), and Joint Implementation, aim at reducing the costs of meeting emission targets by allowing for geographical and temporal flexibility (Dutschke & Michaelowa 1998).

The Clean Development Mechanism is the outcome of lengthy and delicate international negotiations. It represents a compromise between the aspirations of developing countries for development on the one hand and the desire for industrialised countries to meet their emission target in an economically efficient manner on the other. The CDM has two objectives, to offset Greenhouse Gas (GHG) emissions produced in developed countries, and to promote sustainable development in developing countries, as stated in the article 12 of the Kyoto Protocol (UNFCCC 1997, p. 11).

The CDM was originally seen as of particular interest for developing countries. Indeed, the fear for environmental measures hampering development would vanish if climate and development policies could converge. However, the question of whether climate and development objectives are compatible or in contradiction is open to debate (see e.g., Michaelowa and Michaelowa (2007)).

The effective contribution of CDM projects to sustainable development is being questioned, giving rise to a series of measures which aim at promoting CDM activities with broader sustainable development dividends. Attempts to evaluate the contribution of CDM projects to sustainable development exist (see e.g., Olhoff et al. (2004); Olsen and Fenhann (2008); Sutter and Parreño (2007). This paper contributes to this debate by comparing CDM activities with particular attributes to ordinary ones. It does so by applying a multi-criteria methodology in order to evaluate how labelled projects perform with respects to sustainability criteria in comparison to similar non-labelled projects.

In section 7.2, the current status of the CDM portfolio is portrayed and its challenges briefly discussed. Section 7.3 introduces initiatives promoting CDM activities delivering broad sustainable development dividends. The methodology applied in the framework of this research is depicted in section 7.4. The projects evaluated are presented in section 7.5. The evaluation, analysis and discussion feature section 7.6, and the conclusions are presented in section 7.7.

7.2. The current CDM portfolio and its challenges

According to the literature (e.g. Boyd et al. 2007; Cosbey et al. 2005; Olsen 2007; Schneider 2007; Sterk 2008; Sutter and Parreño 2007), a number of CDM projects, including some already approved, are under-performing in terms of contribution to local sustainable development criteria.

They represent, for instance, end-of-pipe adjustments of industrial processes to capture gases with a very high greenhouse effect. These kinds of projects are not an issue as such, in the sense that they effectively contribute to a reduction of GHG released to the atmosphere. However, they are accompanied by very meagre benefits in terms of local sustainable development (Schneider 2007). It is argued that such projects represent almost no technological transfer, induce only low capital investment, promote almost no additional employment and their contribution to social sustainable development is meagre or nil. The relatively high potential of delivering Certified Emission Reductions (CER) from those end-of-pipe fix types of projects, together with their low costs, could trigger negative effects on the emerging market of emission credits, driving down prices by saturating the market (Olsen 2007). This claim is however yet to be empirically demonstrated (Cosbey et al. 2006). Other projects recognised with higher local sustainable development profits, like renewable energy projects for instance, could nevertheless be strongly undermined (Sterk & Wittneben 2005). Other authors (e.g., Sterk 2008) argue, however, that the contribution of offset mechanisms to sustainable development is more related to their design than typology.

The CDM procedure does not formally define sustainability criteria, in contrast to the other objective of the CDM, greenhouse gas offset, whose operationalisation is clearly defined and monitored. The assessment of the contribution to sustainable development of the projects is a sovereign matter of the host-country. *[…] it is to the host Party's prerogative to confirm whether a clean development mechanism project activity assists it in achieving sustainable development, […]* (UNFCCC 2002). By not clearly defining the sustainable development criteria required for the CDM, the United Nations Framework Convention on Climate Change (UNFCCC) allows, rightly so, for the host-country of a CDM project to adjust those criteria according to national development priorities. On a less optimistic view, much uncertainty and inconsistency arise from the lack of coordination between the requirements from host-countries.

Although sustainable development attributes are politically desired, they are not explicitly incorporated in the core structure of the CDM (Boyd et al. 2007). That is, beside the approval stage by the host-country authorities, there are no formal requirements to fulfil in terms of contribution to sustainable development, and therefore also not *ex-post* verification.

The factors that would lead to the acceptance or the refusal of the projects are thus strongly dependent on national values, and could eventually suffer from the influence of strong stakeholders (Olsen 2007). The decision for acceptance could be influenced by other factors, such as incentive for foreign investments, hence disregarding social and environmental aspects and therefore defeating or undermining the potential positive influence on local sustainable development sought by the CDM.

The risk of having different host-countries competing in order to attract CDM by easing the minimum criteria is real and could lead to the sometimes called 'Race to the Bottom' (Sutter 2003; Pearson 2007). The potential host-country has to define a policy balancing the short-term benefits of foreign investments and the long-term dividends of sustainable development.

There is a threat for the market in itself not to be able to yield sufficient projects with high sustainable development values (Olsen 2007; Sutter & Parreño 2007), and thus for the portfolio to be mainly driven by the economic attractiveness of the potential projects (Schneider 2007). Indeed, a few projects with low local positive effects but high CERs, could weaken the opportunity for a greater overall sustainable development outcome (Burian 2006).

Let's consider the following illustrative example. One project capturing a gas (Hydrofluorocarbon, HFC) with a very high global warming potential alone will deliver as many CERs as nearly 200 biomass energy projects together[136]. Therefore, in the market-based mechanism in which the CDMs evolve, one single project with low local sustainable development benefits can rival a multitude of other projects and their combined recognised broad sustainable development dividends.

The unequal distribution of CDM projects throughout developing countries is another source of concern (For data on project distribution, see Boyd et al. 2007; Fenhann 2008; UNDP 2006). Indeed, the great majority of CDM projects seem to target developing countries with strong economies, such as China, India, and Brazil in particular, those countries being the ones where a large amount of the Foreign Direct Investment already flows to (Ellis, Corfee-Morlot & Winkler 2004).

According to Ellis et al. (2004), the impoverished countries which are unable to attract foreign investments also don't seem to be in a position of generating interest in CDM project investments. Some of the poorest countries lack the institutional capacity required to become potential host-countries (Kim 2004). From a development policy point of view, some countries located in Sub-

[136] Project for HFC23 Decomposition at Changshu 3F Zhonghao New Chemical Materials Co. Ltd. (10437 ktCO_2/yr), 199 biomass energy projects registered (10976 ktCO_2/yr in total), own compilation of data from Fenhann (2008), status as of 1 April 2008.

Saharan and Southern Asian regions seem to have the greatest need for foreign investment. The CDM, in its current form, has generated little activities in those regions thus far.

Another concern from critics in developing countries is that the market is likely to promote the most economic options, the sometimes so-called low-hanging fruits (Cosbey et al. 2005). Assuming that, at a later stage, developing countries will also have to comply with some form of defined emission caps, those countries would only have more costly options available in order to do so (Rose, Bulte & Folmer 1999; Muller 2007), thus representing a paradoxical and contra-productive effect from a development assistance viewpoint. This claim is however refuted by Germain et al. (2007).

7.3. Initiatives addressing the CDM shortcomings

In response to the perception that mainstream CDM projects might under perform in terms of sustainable development, some institutions proposed to overcome those shortcomings by encouraging activities which are accompanied by broad and substantial contribution to sustainable development in host-countries. In this regard, labelling appears to be a promising complement to enhance projects with specific features (Muller 2008). Also, special funds target projects with specific characteristics, such as sustainability benefits or located in underprivileged countries.

In the current framework, a monetary value is only attributed to one of the dual objective of the CDM, namely the reduction of greenhouse gases. Premium markets seem to be an attractive option for giving a value to the second objective, which is to promote sustainable development (Schneider 2007). Indeed, the quality of the projects is likely to have an influence on the price of the Certified Emission Reductions delivered.

Sutter (2003) and Muller (2008) review sustainability labels and indicators. Relevant to this research are the Gold Standard label and Community Development Carbon Fund, since those two initiatives aim at promoting sustainable development dividends at local level and do feature registered CDM projects. Other promising initiatives are the recently launched the MDG Carbon Facility and the CCB Standards. There is, however, no CDM project at registration stage from those initiatives as yet[137].

7.3.1. Gold Standard

The Gold Standard[138] proposes a methodology to develop high-quality emission reduction projects with high environmental integrity and secured local social, environmental and economic benefits (Schlup 2005). First initiated by the World Wide Fund for Nature (WWF), the Gold Standard is owned and managed by an international coalition of non-governmental organisations. This innovative approach intends to provide project developers with a tool that allows for ensuring the delivery of credible projects with real benefits for the host-country (Gold Standard 2003).

Under the framework of the CDM, the Gold Standard is an add-on methodology which aspires at fostering broad sustainable development dividends at local level. This non-profit organisation's initiative, of which the use is free of charge, seeks to develop a label that represents the best-practice benchmark for the CDM, by proposing a rigorous assessment framework which is directly compatible with the CDM project cycle. The objectives of the Gold Standard are: 1) ensuring the off-set of the GHG by assessing the additionality in a conservative manner, 2) promoting low-carbon energy systems, and 3) supporting sustainable development in the host-countries. The concept is based on the assumption that, left to the market forces, the CDM does not significantly contribute to sustainable development.

In order to ensure the sustainable development benefits of the project activities, the evaluation of the Gold Standard includes three interdependent elements, namely a sustainability matrix, an Environmental Impact Assessment (EIA), and a stakeholder consultation (Gold Standard 2003). The

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137 Based on personal communication, 1 June 2008 (CCB Standards), 23 April 2008 (MDG Carbon Facility).

138 For more detailed information on the Gold Standard, see: http://www.cdmgoldstandard.org/index.php.

sustainability matrix allows for a simple participatory assessment of the project's contribution to sustainable development. An EIA is performed either when the host-country's regulations require it or when environmental pre-screening or initial stakeholder consultations demonstrate that the impacts are likely to be significant. The participatory approach represents a crucial feature in ensuring that the local sustainability benefits are real. As well, the involvement of the stakeholders reduces the risk of oppositions and delays in a later stage of the project, an argument which is often brought forward to project developers.

It is argued that the Gold Standard addresses four loopholes of the CDM (Langrock & Sterk 2003; Sterk & Langrock 2003). First, it limits the scope to certain types of projects, namely renewable energy and energy efficiency, because specific project activities are renowned for having a higher risk of climatic, environmental or social impacts. Second, as many NGOs dispute the validity of the demonstration of additionality for several projects already approved, the Gold Standard proposes a conservative approach in this regard. Third, the importance of the stakeholder participation is recognised. And forth, the contribution to real sustainable development dividends is reinforced. On the down side, it is also argued that if CERs from Gold Standard projects become notably more costly than ordinary ones, it may be difficult to find buyers.

At the date of writing (April 2008), only 6 registered CDM projects received the Gold Standard certification. They are located in China, Honduras, India, and South Africa. More projects applying the Gold Standard methodology find themselves in an advance stage, but are currently held back by financial and institutional difficulties. Although this niche market might stay marginal, there seems to be strong interest in acquiring premium Gold Standard CER (GTZ 2005).

7.3.2. Community Development Carbon Fund

Another initiative, the World Bank's Community Development Carbon Fund (CDCF)[139], targets small-scale projects located in underprivileged environments. It aims at fostering broad sustainable development benefits while seeking to reduce the unequal distribution of projects.

Small-scale CDM projects seem to entail a relatively high contribution to sustainable development at community level. However, because of the transaction costs, small-scale projects are likely to be rejected by the market if not benefiting from external support (WB, undated). The CDCF offers project developers premium prices for projects that deliver demonstrable community benefits (Bishop 2007).

The fund is designed with the goal of purchasing emission reductions from CDM projects which give the opportunity to communities in developing and least-developed countries to benefit from new investments in clean technologies. The CDCF aims at encouraging sustainable development while promoting a more even distribution of the benefits throughout countries as well as within the host-countries. Also noteworthy, although going beyond the scope of this study, the CDCF implements capacity building measures in order to reduce investment risks, as well as to facilitate project development and replication (WB, undated) through its program CDCFplus.

The CDCF screening ensures that the project is located in a developing country which is part of the UNFCCC, that no more than 10% of the Fund's assets contribute to projects in the same country, that a minimum of 25% of the Fund is dedicated to projects in Least-Developed Countries or in other countries if these projects provide demonstrable benefits to the poorer communities of those countries, and finally, that the projects comply with the small-scale definition stated in the Marrakesh Accords.

At the date of writing (April 2008), about two dozen projects were at validation stage, with 10 being already registered. The projects are located in Latin America (Argentina, Honduras and Peru), Africa (Kenya, Nigeria), Asia (China, India and Nepal), and Eastern Europe (Moldova).

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139 For more detailed information on the Community Development Carbon Fund, see: http://carbonfinance.org/Router.cfm?Page=CDCF&FID=9709&ItemID=9709.

7.4. Methodology

The approach exposed hereafter allows for a discussion on the potential benefits of those initiatives that aim at addressing the CDM shortcomings in terms of sustainable development contribution. This analysis claims in no way to provide an absolute evaluation of each projects contribution of to sustainable development as such. Rather, it allows for a consistent comparison between projects benefiting from those initiatives, and others that do not. Also, this analysis being *ex-ante*, what is actually evaluated is the potential contribution to sustainable development (Cosbey et al. 2006), rather than the contribution itself, which can on only be evaluated *ex-post*[140].

Sustainable development is multi-dimensional in its very nature. Hence, the evaluation of a project's influence on sustainable development requires the examination of several aspects. Therefore, a multi-criteria approach appears to be ideally suited to such analysis.

Also, there is no common unit of measurement in regards to sustainable development assessment with which a criterion, for example the number of jobs created or lost, can be evaluated against another, e.g. the impact on natural resources. However, this does not imply incomparability, but rather that the comparison across the values is weak and can only, or should preferably, be performed without the use of a single type of measure. Multi-criteria evaluation proposes methodological tools that allows for dealing with the incommensurability of values (Martinez-Alier, Munda & O'Neill 1998).

Multi-criteria assessment (MCA) techniques help to deal with complexity (Afgan & Carvalho 2002) by establishing preferences between alternatives to serve a predefined objective. In practice, it is unlikely for any given option, or project, to perform superior in every single criteria. MCA is designed to establish preferences between options for which measurable independent criteria have been defined. The approach doesn't solve all the issues related to multi-aspects evaluation and nor does it reduce the uncertainty linked to such assessment. Nevertheless, it assists in structuring the problem (Cavallaro 2005) and allows for a clear and transparent appraisal and therefore has a clear advantage over informal judgments.

The assessment of a project's contribution to sustainable development would require context-specific criteria, as well as a context-specific definition of sustainable development. However, for the purpose of this study, the same approach and the same set of criteria is used for the evaluation of all the projects in order to allow for a comparison amongst them. This evaluation therefore only allows for partially capturing the potential impacts in terms of local sustainable development.

Elements of the method used are inspired by existing work. Sutter (2003) suggests a method, the so-called Multi-Attributive Assessment of CDM (MATA-CDM), which itself reposes on the Multi-Attributive Utility Theory (MAUT) framework, that is tailor-cut for the evaluation of CDM projects. The MATA-CDM methodology, which includes a proposed set of criteria, assists in making explicit the contribution to the different aspects of sustainable development of each studied CDM project thus allowing for a comparison between projects.

The MATA-CDM method implies the design of a utility function for each criterion. The basic principle for the design of the utility functions is that the maximum utility (1) represents the benchmark best-practice. A utility of zero characterises a neutral state where the influence of the project compared to the reference or baseline in negligible. A negative utility signifies a negative impact of the project for that particular criterion.

The way the evaluation is executed here differs from the proposed original MATA-CDM methodology for various reasons. Firstly, the goal of this analysis is not to establish a ranking between projects but rather to compare and discuss the contribution of initiatives aimed at promoting broad sustainable development dividends from CDM projects in relative terms. Therefore, the aggregation to a single final utility is not necessary. The ultimate objective reposes on a comparison of the sustainable

[140] For an example of methodology to validate and certify sustainable development dividends from CDM, see Social Carbon: http://www.ecologica.org.br/mudancas_social.html.

development dividends profiles. In this context, the functions for each criterion are to be understood as a means of scaling the criteria, resulting in scores for each criterion.

Secondly, the assumption of complete compensability is intrinsic to ordinal utility theory, which can be seen as a drawback from certain viewpoints. A bad performance in one criterion is compensated by a better performance in others. This particularity raises the issue of value trade-offs. MAUT models incorporate ratios which define the performance in one criterion that is compensated by another. In MAUT, such trade-offs are implicitly established when designing the individual utility functions. A potential technical incommensurability (Giampietro, Mayumi & Munda 2006) of the indicators might exist. Indeed, the aggregation would imply that it is possible to value the criteria against another, that is, being able to transparently define how much environmental degradation is acceptable if a certain number of jobs are created for instance, and this for every single criterion against every other. This is thus another argument speaking in favour of not aggregating the scores. The stringency of the MATA-CDM was questioned by stakeholders during case studies application because of the issue of trade-off between different criteria (Heuberger et al. 2007). Furthermore, the elimination of that final stage allows for visualising the potential compensative effects (bad performance in one criterion being compensated by good performance in others) hidden in the original approach.

Thirdly, unlike the original methodology, the present study does not claim to assess the contribution of CDM projects to sustainable development as such. Rather it proposes a framework for comparing projects in order to discuss a specific aspect: the effectiveness of initiatives aimed at fostering local sustainable development dividends.

Fourthly, in the MATA-CDM, the weighting of the criteria aims at expressing the relative importance of each criterion (Sutter 2003). Indeed, one criterion could be assumed as more relevant than another in relative terms. However, weightings represent a controversial, and well debated, issue in the framework of multi-criteria assessments. If assigned by an individual, weightings can seem arbitrary and value-driven. On the other hand, weightings derived from participatory processes would be ideal, but difficult to meaningfully implement. A consensus over the set of criteria to be evaluated might be possible under certain conditions. However, in the case of assigning relative importance to criteria, such a consensus is difficult to envisage if a broad range of stakeholders, with possibly conflicting objectives, are represented in the process. If divergences emerge, an aggregation of the values from different stakeholders, like a mean value for instance, might produce an outcome that does not reflect the reality and which masks the heterogeneity of the stakeholder representation. Also and most importantly, some authors (Munda & Nardo 2005; Munda 2008) argue that in a compensatory framework such as the MAUT, using weights to embody intensity of importance represents a theoretical inconsistency. In the case of linear compensatory aggregation models, weights depend on the scale of the criteria and are to be understood as trade-offs, or judgments about compensability and not importance factors. The issue of weights is yet another argument speaking against aggregating the score of the criteria (see also discussion on aggregation in Sharpe (2004)).

And fifthly, in this paper, the results of the evaluation are represented in amoeba-graphs, which is not an instance of the MATA-CDM, for each project type sub-group, allowing to visualize the representation of the sustainability profile of the projects evaluated.

Nonetheless, an advantage of the MATA-CDM, and MAUT methods in general, lies in the fact that the methodology is relatively simple to apply and does not require advanced knowledge in multi-criteria techniques. Therefore, its possible application is wide and not limited to the academic sphere. Also, the MATA-CDM methodology is field-proven. Indeed, this method already demonstrated its potential in several case studies (Heuberger et al. 2007; Sutter & Parreño 2007). Moreover, the method is used in practice. The Uruguayan Designated National Authority (DNA), for example, applies the MATA-CDM for the evaluation of CDM projects in order to decide on whether they sufficiently contribute to sustainable development and thus give their approval or not (Sutter 2003; Heuberger et al. 2007).

For the purpose of this evaluation, the sustainable development criteria used draw from Sutter (2003), with the exception of the criteria Equal Distribution of Project Returns, which is based on Sutter and Parreño (2007) due to its more appropriate operationability based on available project information. The criteria are organised according to the traditional classification of the three pillars of sustainable development. The criteria are listed in Table 7-1, and a more detailed description can be found in Sutter (2003).

Table 7-1: Overview of sustainable development criteria

	Criteria	Abbreviation
Social	Stakeholder participation	SOC1
	Improved service availability	SOC2
	Equal distribution	SOC3
	Capacity development	SOC4
Environmental	Fossil energy resources	ENV1
	Air quality	ENV2
	Water quality	ENV3
	Land resource	ENV4
Economic	Regional economy	ECO1
	Microeconomic efficiency	ECO2
	Employment generation	ECO3
	Sustainable technology transfer	ECO4

It is acknowledged that the choice of the criteria is somewhat arbitrary and reposes on value judgment. However, the set of criteria suggested is based on the experience from existing studies applying the multi-criteria methodology (Sutter 2003; Sutter & Parreño 2007). Moreover, internationally acknowledged sustainability evaluation methods, such as the one suggested by SouthSouthNorth (2003) and the Gold Standard itself, feature similar sets of criteria (for an overview of the literature, see Olsen (2007)). The set of criteria needs to represent a balanced compromise between representativeness and operationality. The scoring functions for the respective criteria are specified in Annex 7-A. The scoring functions are used for making the representation of the sustainable development profiles of the different projects possible in Amoeba graphs.

The data necessary for the evaluation of the projects are derived from the respective Project Design Document (PDD) and associated documents. The PDD is represents the official document submitted by a CDM promoter in the UNFCCC framework. The limitation to one source may seem restrictive. However, this approach presents many advantages. Firstly, the PDD is a public document available on the internet and thus easily accessible. Secondly, the document and its content, unlike unofficial project documents, can be assumed as being fairly reliable. Indeed, the PDD represents the official document submitted to the authoritative body of the CDM, the Executive Board, for approbation of the project. Before this, the PDD has to be reviewed and approved by a so-called Designated Operational Entity, a body accredited by the UNFCCC, to ensure its concordance with the requirements. Furthermore, the procedure requires for the document to be subjected to public comments as well as to take into consideration those comments. Thirdly, the form being standardised, it contains relatively homogenous data. However, information in regard to sustainable development in the PDD is sparse or vague in some cases. Where possible, data from other studies (Sutter 2003; Cosbey et al. 2006; Sutter & Parreño 2007) are used as cross-check. And fourthly, data from PPDs is easily available to the non-specialised community and is a reference for determining from which CDM activities to purchase Certified Emission Reductions for instance.

7.5. Projects evaluated

In order to evaluate the relative potential performance in terms of contribution to local sustainable development of Gold Standard and CDCF projects, they are compared with ordinary CDM projects with similar features. 39 CDM activities were evaluated. Table 7-2 provides and overview of the projects evaluated, mentioning some of their main attributes as well as whether they are a Gold Standard or CDCF activity.

Table 7-2: Overview of CDM projects evaluated

Ref.	Project name	Host country	Type	Sub-type	Methodology	Gold Standard	CDCF
121	Bagepalli CDM Biogas Programme (5500 units of 2 m^3)	India	Biogas	Biogas power	AMS-I.C.		
136	Biogas Sector Partnership Nepal (6500 units) Activity-1	Nepal	Biogas	Biogas power	AMS-I.C.		x
139	Biogas Support Program - Nepal (BSP-Nepal) Activity-2	Nepal	Biogas	Biogas power	AMS-I.C.		x
478	A joint venture project of cogeneration of electricity and hot water using natural gas and biogas produced from on-site wastewater biodigesters	Mexico	Biogas	Biogas power	AMS-I.C.		
777	Energy Efficiency Improvement in Electric Arc Furnace at Indian Seamless Metal Tube Limited (ISMT), Jejuri, Maharashtra	India	EE industry	Iron & steel	AMS-II.D.		
582	India - Vertical Shaft Brick Kiln Cluster Project	India	EE industry	Building materials	AMS-II.D.		x
847	Up-gradation of Gas Turbine 1 (GT 1) and Gas Turbine 2 (GT 2) at co-generation plant of Hazira Gas Processing Complex (HGPC) of Oil and Natural Gas Corporation Limited (ONGC)	India	EE industry	Petrochemicals	AMS-II.D.		
685	Modification of Clinker Cooler for Energy Efficiency Improvement in Cement manufacturing at Binani Cements	India	EE industry	Cement	AMS-II.D.		
707	India-FaL-G Brick and Blocks Project No.1	India	EE industry	Building materials	AMS-II.D.		x
1018	Fuel efficiency improvement in glass melting	India	EE Industry	Glass	AMS-II.D.		
140	Olavarría landfill gas recovery project	Argentina	Landfill gas	Landfill flaring	ACM1		x
1219	Coronel landfill gas capture project	Chile	Landfill gas	Landfill flaring	ACM1		
1442	AESA Misiones (Proactiva Group) Sanitary Landfill Gas Capture and Flaring Project	Argentina	Landfill gas	Landfill flaring	ACM1		
546	SRGEL Non-Conventional Renewable Sources Biomass Power Project	India	Biomass energy	Agricultural residues: other kinds	AMS-I.D.		
298	4.5 MW Biomass (low density Crop Residues) based Power Generation unit of Malavalli Power Plant Pvt Ltd.	India	Biomass energy	Agricultural residues: other kinds	AMS-I.D.	x	
281	4.5 MW Biomass (Agricultural Residue) Based Power Generation Unit of M/s Matrix Power Pvt. Ltd. (MPPL)	India	Biomass energy	Agricultural residues: other kinds	AMS-I.D.		
492	Eecopalsa – biogas recovery and electricity generation from Palm Oil Mill Effluent ponds	Honduras	Biogas	Power	AMS-I.D.+AMS-III.H.	x	
498	SIDPL Methane extraction and Power generation project	India	Biogas	Power	AMS-I.D.+AMS-III.H.		

Ref.	Project name	Host country	Type	Sub-type	Methodology	Gold Standard	CDCF
505	Methane recovery and power generation in a distillery plant	India	Biogas	Power	AMS-I.D.+AMS-III.H.		
159	Moldova biomass heating in rural communities project-no.1	Moldova	EE households		AMS-I.C.+AMS-II.E.+AMS-III.B.		x
160	Moldova Biomass Heating in Rural Communities (Project Design Document No. 2)	Moldova	EE households		AMS-I.C.+AMS-II.E.+AMS-III.B.		x
79	Kuyasa low-cost urban housing energy upgrade project, Khayelitsha	South Africa	EE households		AMS-I.C.+AMS-II.C.+AMS-II.E.	x	
244	Aleo Manali 3 MW Small Hydroelectric Project	India	Hydro	Run of river	AMS-I.D.		
88	Santa Rosa (1,1 MW + 1,5 MW + 1,5 MW)	Peru	Hydro	Run of river	AMS-I.D.		x
35	5 MW Dehar Grid-connected SHP in Himachal Pradesh	India	Hydro	Run of river	AMS-I.D.		
960	"2 X 5 MW Upper khauli & Drinidhar small hydroelectric project for a grid system", Himachal Pradesh	India	Hydro	Run of river	AMS-I.D.		
9	La Esperanza Hydroelectric 12.7 MW small scale project	Honduras	Hydro	Run of river	AMS-I.D.		x
81	"Los Algarrobos" Small-Scale Hydroelectric Project	Panama	Hydro	Run of river	AMS-I.D.		
841	Yunnan Whitewaters Hydropower Development Project	China	Hydro	New dam	ACM2		
904	Guangrun Hydropower Project in Hubei Province	China	Hydro	New dam	ACM2		x
996	Zhoubai Hydroelectric Project	China	Hydro	New dam	ACM2		
1244	The Wulabo 30 MW Wind-Farm Project in Urumqi, Xinjiang of China	China	Wind		ACM2		
1318	Fujian Zhangpu Liuao 45MW Wind Power Project	China	Wind		ACM2	x	
1327	Inner Mongolia Zhuozi 40MW Wind Power Project	China	Wind		ACM2		
310	Bundled Wind power project in Jaisalmer (Rajasthan in India) managed by Enercon (India)Ltd	India	Wind		ACM2		
1269	Ningxia Yinyi 49.50MW Wind-farm Project, China	China	Wind		ACM2	x	
483	Jilin Changling Wind Farm Phase I Project	China	Wind		ACM2		
414	Solar steam for cooking and other applications	India	Solar	Solar cooking	AMS-I.C.	x	
218	CDM Solar Cooker Project Aceh 1	Indonesia	Solar	Solar cooking	AMS-I.C.		

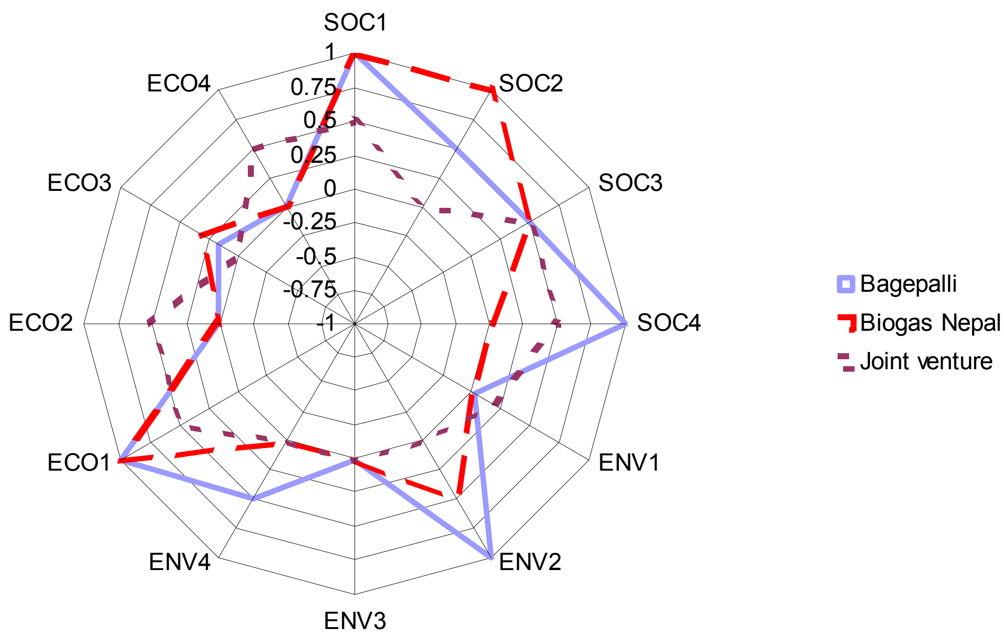
In order to limit the number of projects, and thus arrive to a manageable amount of data, the CDM pipeline (Fenhann 2008) is filtered according to several criteria. Only registered projected are considered. All Gold Standard and CDCF CDM projects are selected. They are compared with non-label projects of similar type. The selection criteria of the CDM pipeline are, chronologically, type, sub-type, and methodology. In the case where the filtering results in a large number of projects, an additional criterion of size ($ktCO_2$/yr) is used to selected CDM activities that are of similar size to the labelled project by selecting the two projects that are directly adjacent to the labelled one in the pipeline.

7.6. Evaluation and discussion

The results of the sustainable development evaluation are presented in Amoeba graphs for each project sub-groups. As guidance for reading the graphs, social development criteria are represented from 12 to 3 o'clock in the diagrams, environmental development from 4 to 7 o'clock, and economic development from 8 to 11 o'clock. CDCF projects are represented in red and Gold Standard in gold, while ordinary projects are in other colours.

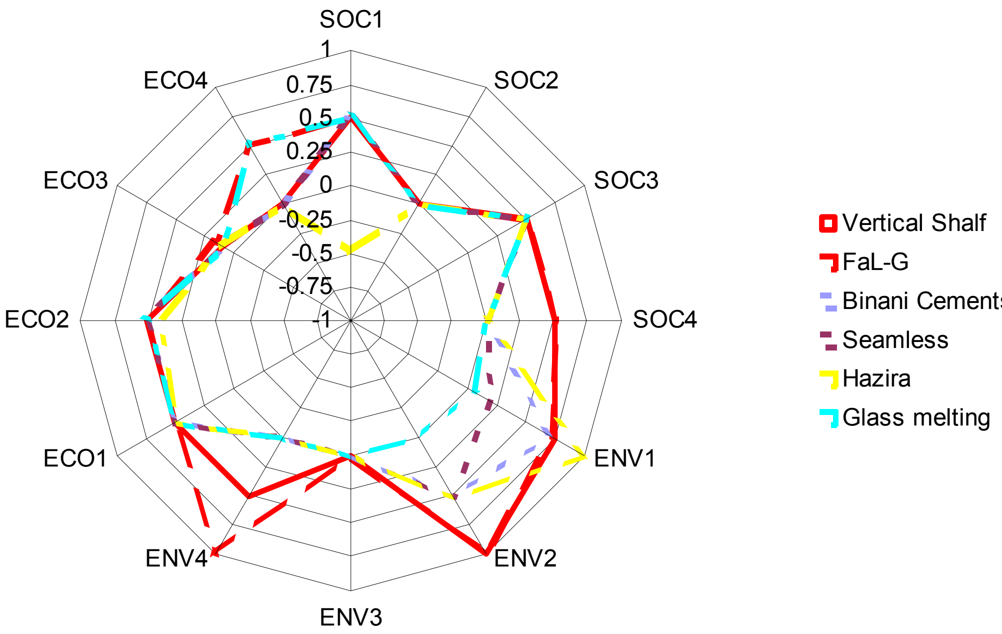
For the biogas subgroup, Figure 7-1 suggests that the sustainable development profile of the Bagepalli project, which is an ordinary CDM activity, outperforms the CDCF project at least for a few criteria, while the other project (Joint venture) seems to perform relatively well in terms of economic criteria, but less well in other indicators. Only one Biogas Nepal project is shown in the graph for clarity since both feature similar sustainable development profile.

Figure 7-1: Sustainable Development profile of CDM projects, type: Biogas thermal energy.



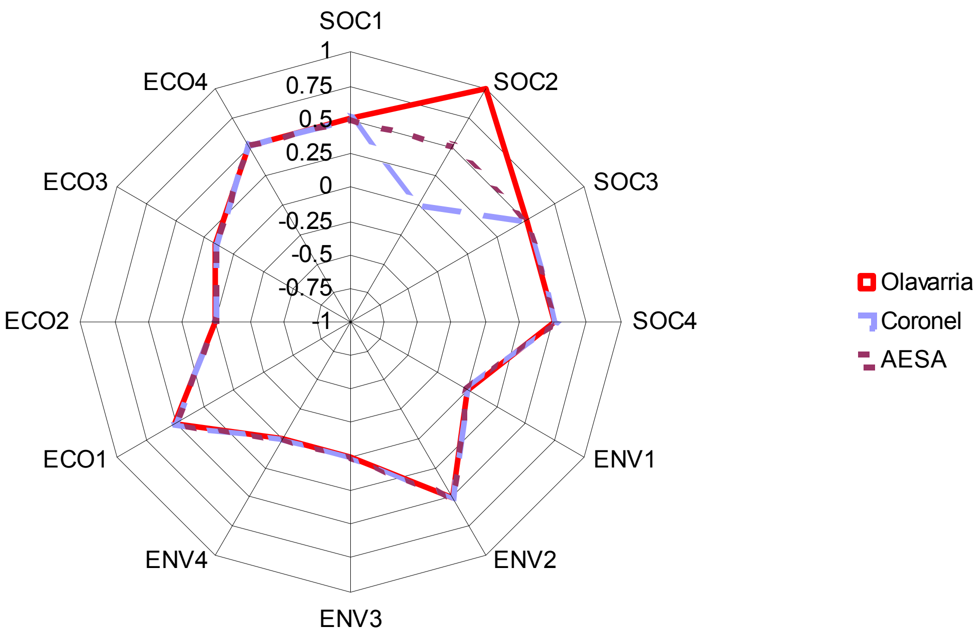
As far as the industrial energy efficiency sub-group is concerned, the two CDCF projects' sustainable development profile is more ample than their opponent's, notably in terms of environmental indicators (Figure 7-2).

Figure 7-2: Sustainable Development profile of CDM projects, type: Energy efficiency industry



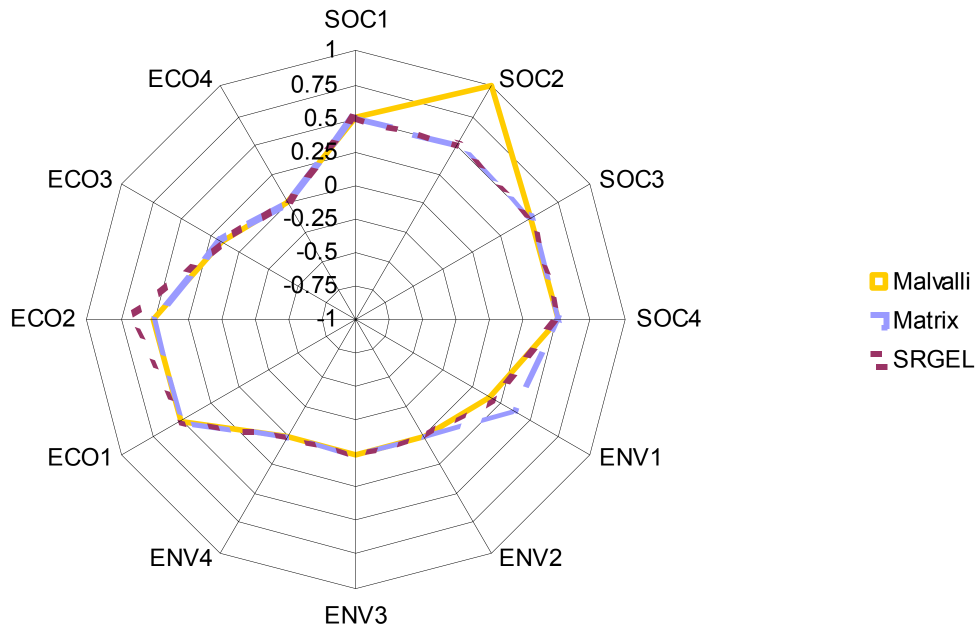
In regard to the landfill diagram (Figure 7-3), all three projects match closely, with the exception of the one social criterion (improved service availability) for which the CDCF activity surpass the other two projects.

Figure 7-3: Sustainable Development profile of CDM projects, type: Landfill



The picture in regard to the biomass projects (Figure 7-4) looks relatively balanced, with the Gold Standard outperforming the other two projects only in one criterion (improved service availability), and scoring less in a couple of others.

Figure 7-4: Sustainable Development profile of CDM projects, type: Biomass agriculture



The biogas for electricity generation diagram (Figure 7-5) presents a similar outcome. The sustainable development profiles of the three projects are closely matching, except for a few criteria for which the Gold Standard project seems to perform better.

Figure 7-5: Sustainable Development profile of CDM projects, type: Biogas electricity

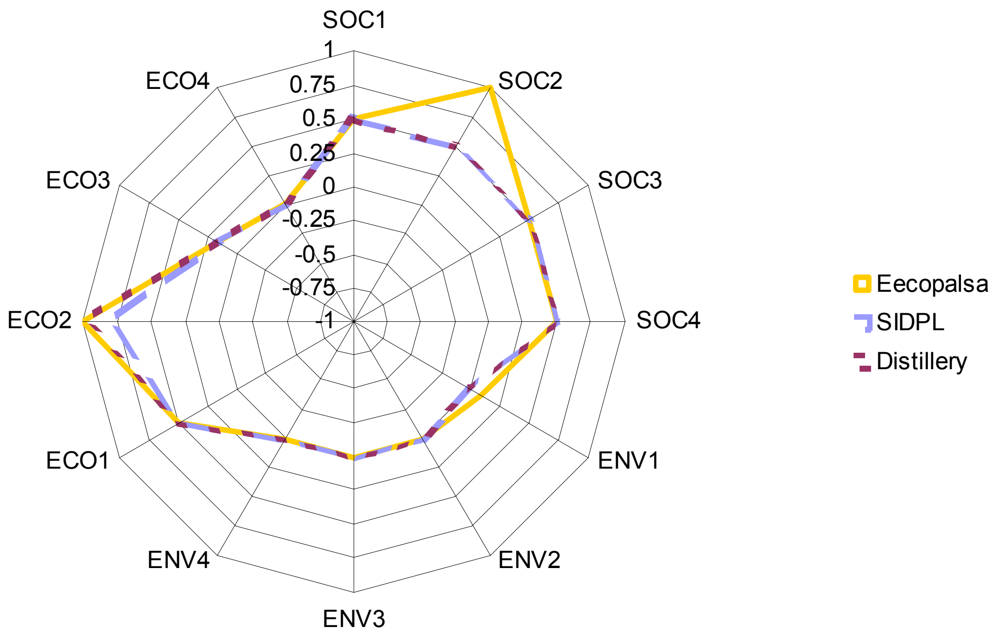
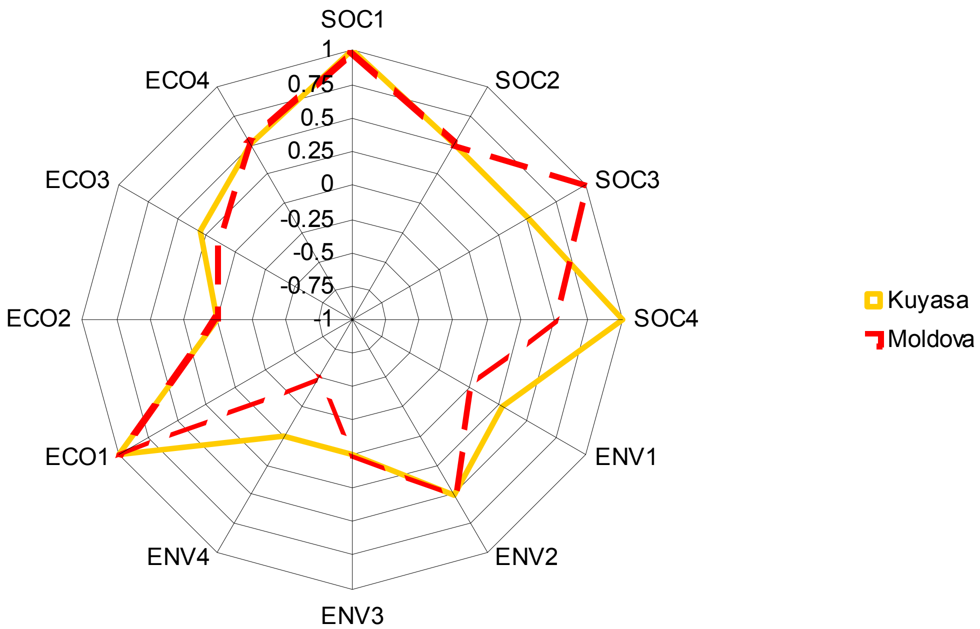


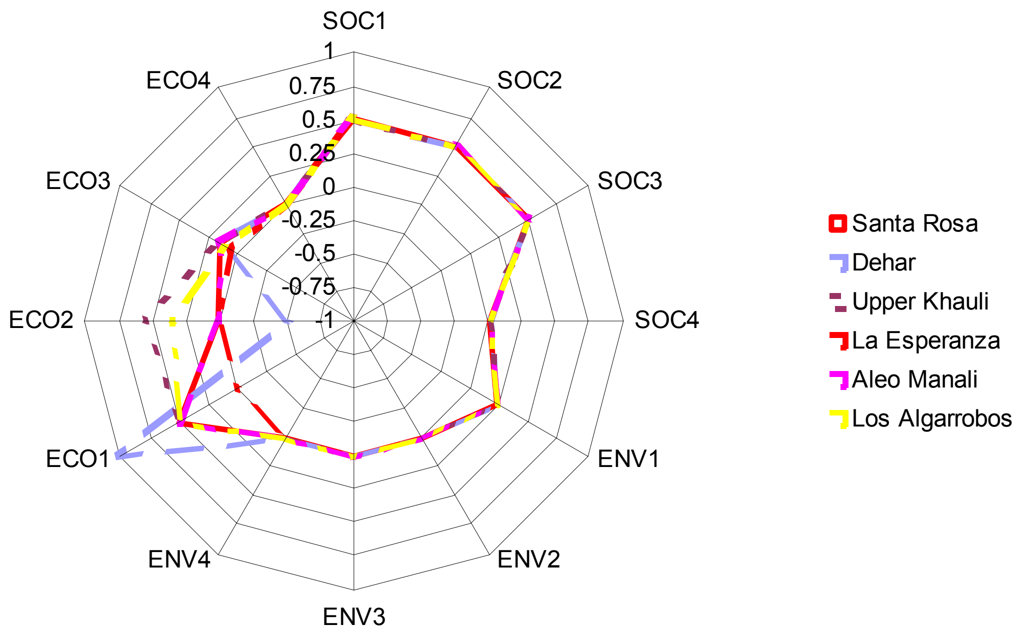
Figure 7-6 for the energy efficiency sub-group features both a Gold Standard and a CDCF projects. The Gold Standard activity outperforms the CDCF project in some criteria, and the opposite statement is valid for one criterion. Both projects feature a similar profile overall, with a slight advantage for the Gold Standard.

Figure 7-6: Sustainable Development profile of CDM projects, type: Energy efficiency buildings



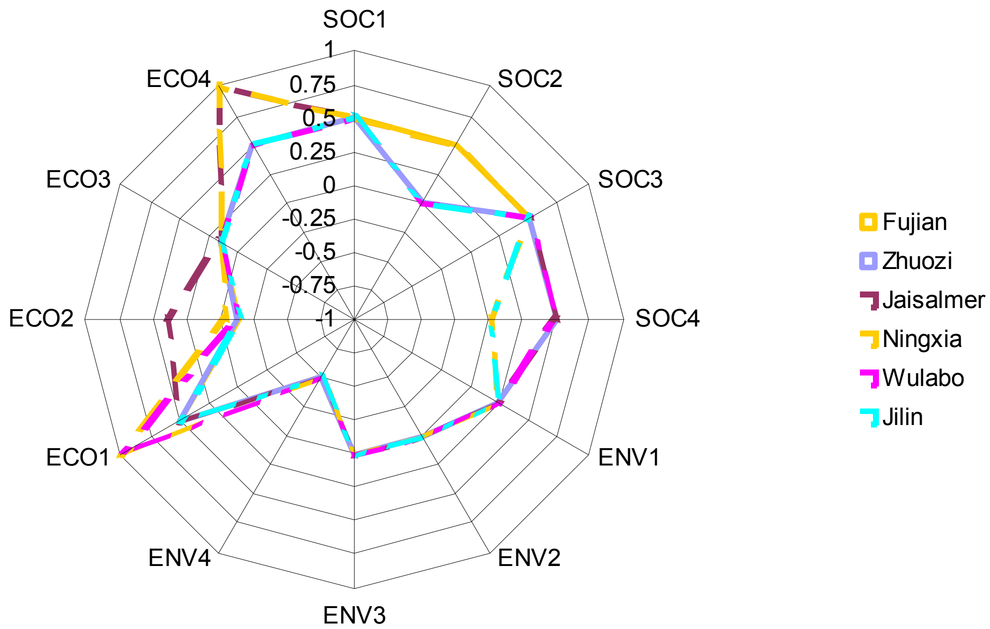
The two CDCF hydro projects' profiles (Figure 7-7) seem well distributed over the different criteria. Interestingly, the Upper Khauli project appears to outperform both CDCF activities in terms of sustainable development profile. Noteworthy is the misbalanced profile of the Dehar project.

Figure 7-7: Sustainable Development profile of CDM projects, type: Hydro run of river



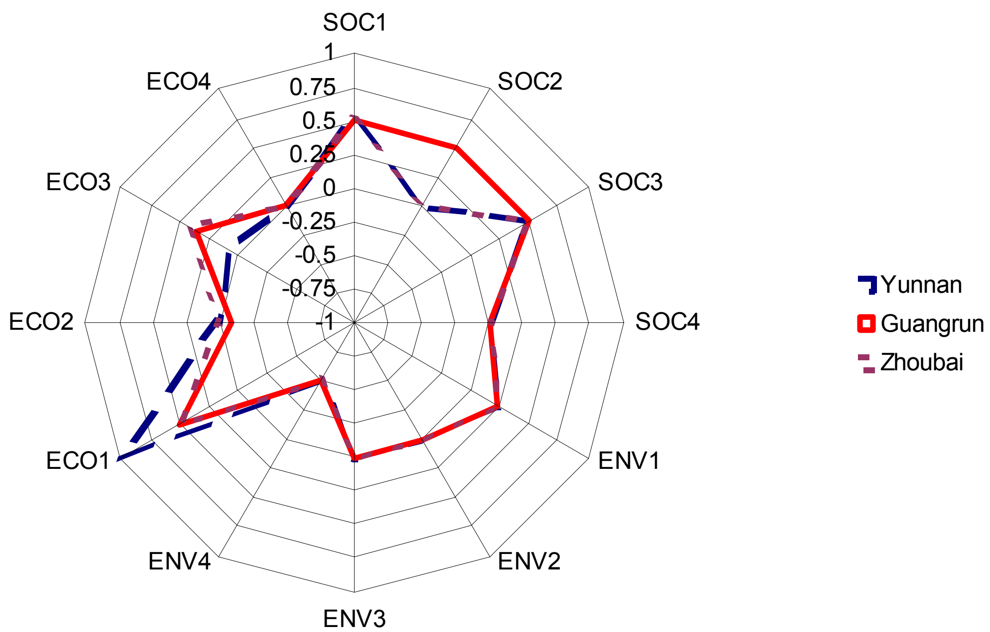
The two Gold Standard activities seem to outperform the other wind projects (Figure 7-8), but again not uniformly in all criteria.

Figure 7-8: Sustainable Development profile of CDM projects, type: Wind



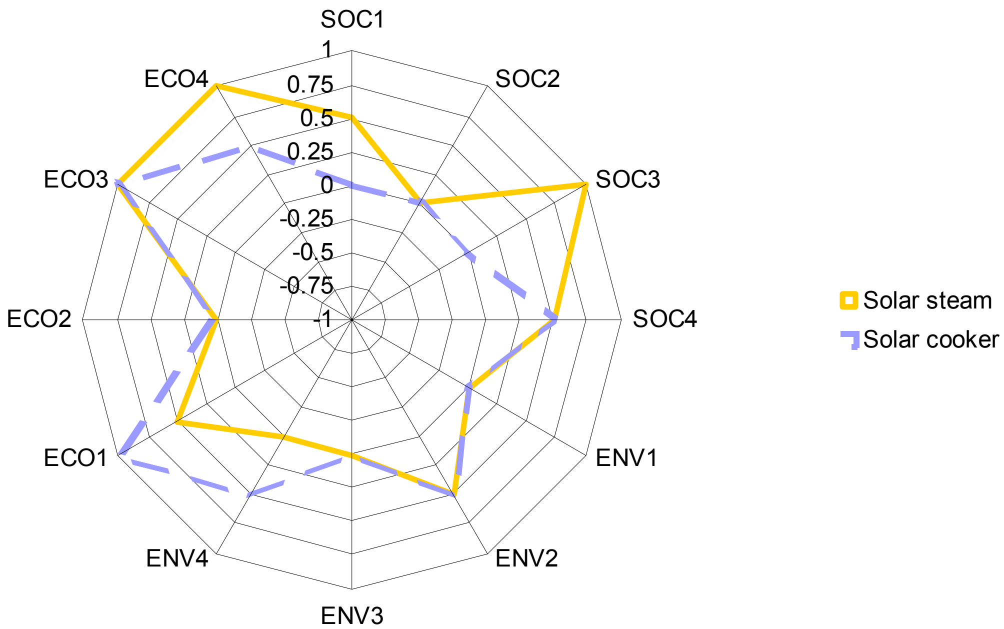
The CDCF project performs similarly overall to the non-label activities in Figure 7-9.

Figure 7-9: Sustainable Development profile of CDM projects, type: Hydro new dam



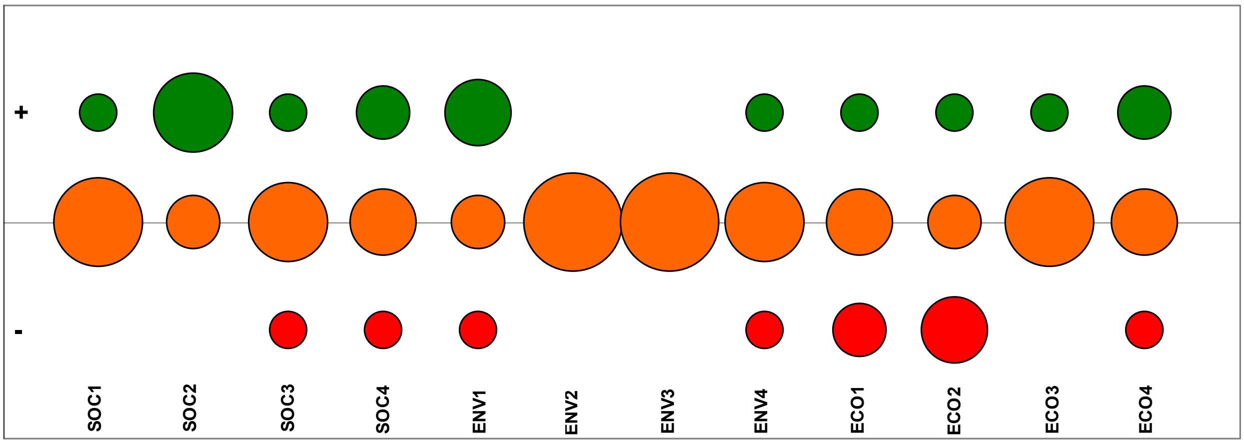
The Gold Standard project outdoes the non-labelled one in several criteria, whereas not in others in the solar sub-group (Figure 7-10).

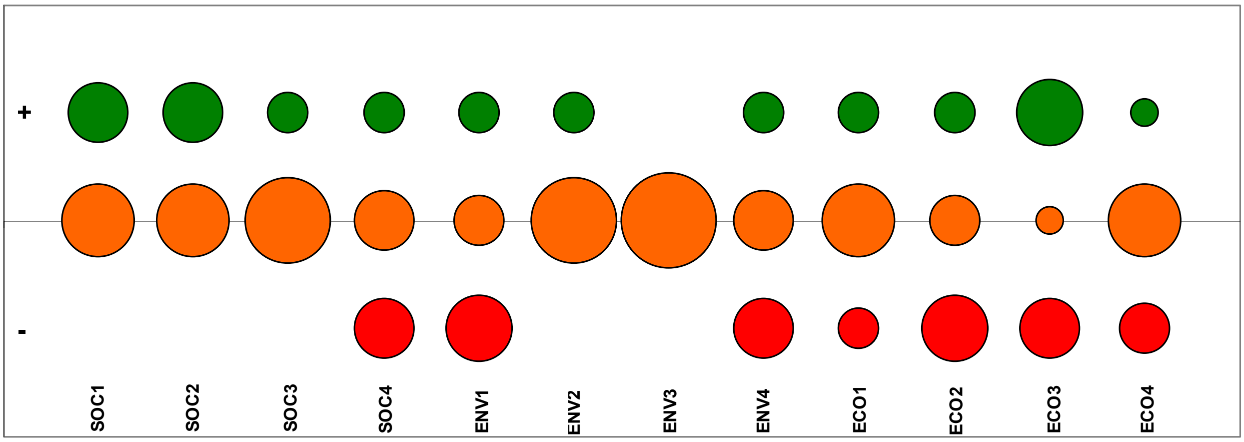
Figure 7-10: Sustainable Development profile of CDM projects, type: Solar



This section formalises the comparison between projects with and without special attributes. The scores of labelled projects in each criterion individually, in order to respect the incommensurability of the criteria, are compared with the average score of the respective sub-group projects in the same criterion. The results are shown in Figure 7-11. The sustainable development criteria are represented on the x-axis. The y-axis represents whether the labelled project outperforms (+, in green), equals (on the axis, in orange), or underperforms (-, in red) compared to the average. The dots are proportional to the number of instances, considering all sub-groups together. For example, in regard to the criterion SOC1, the scores of Gold Standard projects equal the average of their respective sub-groups in many instances, outperform it in a few instances, and are never below the average.

Figure 7-11: Comparison of Sustainable Development contribution of Gold Standard CDM projects (top panel) and CDCF projects (bottom panel) with the average score of similar projects





From this diagrams (Figure 7-11), one can deduct that in most instances, labelled projects perform similarly to the average of their respective sub-groups. Both the Gold Standard and the CDCF feature a slightly better performance overall when compared to similar projects, the advantage being somewhat more marked for the Gold Standard.

Going into the details of the individual indicators, one can note a better contribution to criteria related to social sustainable development of labelled projects, and mixed results for the environmental criteria. In terms of economic indicators, the CDCF activities most often score under the average. This latter finding is not counter-intuitive since the CDCF aims at promoting activities that would otherwise be likely to be rejected by the market.

7.7. Conclusion

The CDM seems to have been very successful in contributing to the development of a global carbon market, allowing for temporal and spatial flexibility in achieving emission reduction targets. On the other hand, its role in assisting host-countries in their effort to promote sustainable development is being questioned. According to critics, the contribution to sustainable development of several Clean Development Mechanism projects is disappointing. Several actions have taken place intending to remedy to some of those shortcomings. The Gold Standard rewards best-practice CDM projects. The CDCF promotes CDM activities located in underprivileged communities. This analysis compares projects with special attributes with ordinary ones.

Since labelled Certified Emission Reductions are likely to be more costly than those delivered by ordinary CDM activities, it is legitimate to evaluate whether their contribution in terms of sustainable development differs from non-labelled projects. It is important to underline here, however, that the added-value of labelled projects is also be reflected in other issues. For example, the Gold Standard methodology features additional requirement in terms of additionality demonstration. Such effects go beyond the scope of this study and are thus not captured in this analysis since it focuses exclusively on sustainable development attributes.

Multi-criteria seems particularly appropriate for evaluating the multi-dimensionality of sustainable development. The MATA-CDM provides a methodology which allows for a straightforward and consistent appraisal of the projects' contribution to sustainable development. The methodology applied in this research derives from the MATA-CDM and is adapted to the specific requirements of this evaluation, with a particular emphasis on the respect of the principle of incommensurability of the different indicators.

The evaluation carried out in this research suggests that, based on the sample of projects evaluated, the sustainable development profile of premium CDM projects tends to be comparable or slightly more ample than similar ordinary projects. Labelled projects do not, however, drastically out perform non-labelled ones. Also, the distinction between projects might very well be within the range of uncertainty intrinsic to such assessment. The contribution of labelled projects to social sustainable development tends to outdo comparable ordinary activities, whereas the contrary holds for economic criteria of sustainable development.

It must be noted that this evaluation compares CDM activities which are believed to be the most promising in terms of sustainable development contribution, such as renewable energy and energy efficiency projects for instance. Also, most projects evaluated are small-scale activities. Industrial end-of-the-pipe adjustments for instance, which are subject to fierce critics, are not the focus of the Gold Standard or the CDCF, and thus do not appear in this analysis. There are reasons to believe that such projects would feature a significantly different sustainable development profile.

Considering that the CDM is at best carbon-neutral, its contribution to sustainable development is essential. Since the CDM is a market-based mechanism, it is likely to be driven by factors others than the contribution to sustainable development in the host-country since those are not marketed. Means to differentiate the quality of the projects, such as labels, therefore provide valuable signals to investors, project developers, and potential certificates buyers, provided that such labels are credible.

Albeit the current shortcomings, a framework such as the CDM appears to have a great potential as effective market instrument, including in the medium term (post-Kyoto). It is therefore of critical importance to ensure that both objectives, greenhouse gas emission reduction and contribution to sustainable development, effectively enfold their full potential. While the former objective is clearly regulated, clearer guidance in terms of making the assessment of the potential contribution to sustainable development, through a set of quantifiable indicators for instance, would be most useful. Guidelines in that regard could be integrated into the validation and verification processes.

Acknowledgments

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Annex 7-A: Scoring functions for the sustainable development criteria

$$S_{SOC1}(P) = \begin{cases} 1 & \text{if Stakeholders can participate actively in the decision process} \\ 0.5 & \text{if Stakeholders are invited to give inputs and raise concerns} \\ 0 & \text{if Stakeholders are informed} \\ -0.5 & \text{if Stakeholders are only informed upon request} \\ -1 & \text{if Stakeholders are not involved at all; no access to data is possible} \end{cases}$$

$$S_{SOC2}(P) = \begin{cases} 1 & \text{if Significant increase in availability of important services} \\ 0.5 & \text{if Moderate increase in the availability of important services} \\ 0 & \text{if No change compared to baseline} \\ -0.5 & \text{if Moderate decrease in the availability of important services} \\ -1 & \text{if Significant decrease in the availability of important services} \end{cases}$$

$$S_{SOC3}(P) = \begin{cases} 1 & \text{if The largest fraction of the profits from CER revenues flows to the poorer 50\% of the host-country population (e.g. the project owner is a small producer, local association)} \\ 0.5 & \text{if The largest fraction of the profits from CER revenues flows to the host-country population (e.g. the project owner is a corporation of the host-country, a host-country owned entity)} \\ 0 & \text{if The largest fraction of the profits from CER revenues flows to people outside the host-country (e.g. the project owner is an internationally hold corporation)} \\ -0.5 & \text{if The project activities reduce revenues of the host-country} \\ -1 & \text{if The project activities reduce revenues of the poorer 50\% of the host-country population} \end{cases}$$

$$S_{SOC4}(P) = \begin{cases} 1 & \text{if Significant increase in opportunities for capacity development} \\ 0.5 & \text{if Moderate increase in opportunities for capacity development} \\ 0 & \text{if No change compared to baseline} \\ -0.5 & \text{if Moderate decrease in opportunities for capacity development} \\ -1 & \text{if Significant decrease in opportunities for capacity development} \end{cases}$$

$$S_{ENV1}(P) = \frac{tC_B - tC_P}{CER * 0.744}$$

where: tC_B : tons of coal equivalent per year used by baseline; tC_P : tons of coal equivalent per year used by project; CER : Certified Emission Reduction

$$S_{ENV2}(P) = \begin{cases} 1 & \text{if Significant decrease of air pollutant emissions} \\ 0.5 & \text{if Moderate decrease of air pollutant emissions} \\ 0 & \text{if No change compared to baseline} \\ -0.5 & \text{if Moderate increase of air pollutant emissions} \\ -1 & \text{if Significant increase of air pollutant emissions} \end{cases}$$

$$S_{ENV3}(P) = \begin{cases} 1 & \text{if Significant decrease of pressure on the water supply} \\ 0.5 & \text{if Moderate decrease of pressure on the water supply} \\ 0 & \text{if No change compared to baseline} \\ -0.5 & \text{if Moderate increase of pressure on the water supply} \\ -1 & \text{if Significant increase of pressure on the water supply} \end{cases}$$

$$S_{ENV4}(P) = \begin{cases} 1 & \text{if Significant decrease of pressure on land resources} \\ 0.5 & \text{if Moderate decrease of pressure on land resources} \\ 0 & \text{if No change compared to baseline} \\ -0.5 & \text{if Moderate increase of pressure on land resources} \\ -1 & \text{if Significant increase of pressure on land resources} \end{cases}$$

$$S_{ECO1}(P) = \begin{cases} 1 & \text{if Project location economically disadvantaged} \\ 0.5 & \text{if Project location economically average} \\ 0 & \text{if Project location economically privileged} \\ -0.5 & \text{if Project location economically average which hinders development of disadvantaged location} \\ -1 & \text{if Project location economically privileged which hinders development of disadvantaged location} \end{cases}$$

$$S_{ECO2}(P) = \begin{cases} 1 & \text{if IRR} > 20 \\ \frac{IRR}{10} - 1 & \text{if IRR } [0, 20] \\ -1 & \text{if IRR} < 0 \end{cases}$$

where: *IRR* : Internal Rate of Return [%]

$$S_{ECO3}(P) = \frac{J_P - J_B}{CER * 0.22}$$

where: *IRR* : J_P : man-months created by the project; J_B : man-months created by the baseline case; *CER* : Certified Emission Reduction

$$S_{ECO4}(P) = \begin{cases} 1 & \text{if The technology is innovative and the capacity exists locally to maintain and manage it} \\ 0.5 & \text{if The technology is innovative but external assistance is require to develop local skills} \\ 0 & \text{if There is no technological transfer or the innovative technology requires durable external assistance} \\ -0.5 & \text{if External skills must be imported and the project creates dependence} \\ -1 & \text{if The new technology cannot be maintained and managed in the long-term} \end{cases}$$

where *S* is the scoring function of a CDM project *P* for a sustainable development criteria (e.g. *SOC1*).

8. Further Work

Whilst the research presented in the previous sections sheds light on a number of aspects related to the nexus between energy and sustainable development, it also touches upon various issues that deserve additional scrutiny. Without claiming to be all-embracing, this section delineates a selection of areas, in addition to those identified in the respective sections, where further work would be desirable as natural follow up to this dissertation.

8.1. Energy for productive uses and income generation

Socio-economic development, as well as economic activity, is contingent on access to reliable, affordable energy services. Energy is essential at all levels of development, ranging from catering for basic human needs to fueling modern society needs.

Significant efforts are dedicated to understanding the link between access to energy and basic needs such as cooking and space heating. Also, the provision of energy to sustain the economic development of industrialized countries lies at the heart of the political agenda. Access to energy services for the intermediate level (level 2 in Figure 8-1) of development deserves additional attention.

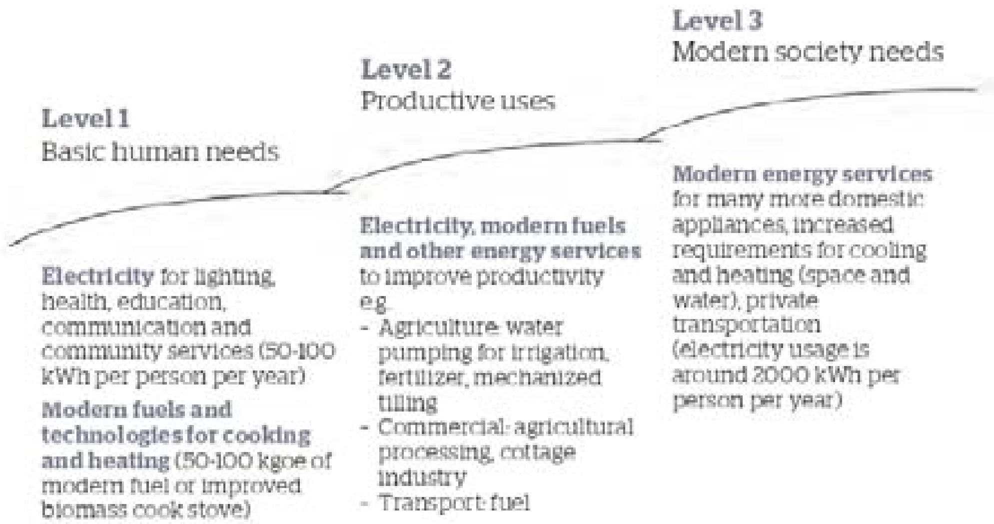

Figure 8-1: Incremental levels of access to energy services

Source: AGECC (2010, p. 13)

Once basic needs are fulfilled, electricity, modern fuels and other energy services represent an important factor to improve productivity. Possible productive uses for the poor that can be enhanced through the provision of adequate energy services include improved agricultural production (e.g. water pumping for irrigation, mechanized tilling) and processing. Facilitating productive activities is a means to improve livelihoods in the poorest countries and a driver of economic development on a sustainable basis.

Providing energy for basic human needs and for productive uses are concepts that are not mutually exclusive. It goes without to mention that people will strive for survival and ensure food and shelter for their families before being concerned by productivity.

Mechanical power has been used for centuries for a number of applications, for instance for water pumping. In recent history, mechanical power has played a crucial role in increasing productivity. Notwithstanding its crucial importance to development, mechanical power is commonly overlooked and under-appreciated. The focus of efforts in promoting development with energy is often set on electricity, and increasingly nowadays on thermal needs (cooking and heating). Mechanical power however generally involves low investment costs and represents an effective way to directly benefit poor people (Bates et al. 2009).

Businesses (factories, farms, trading, transportation, and construction), small and large, represent an engine to growth and poverty alleviation. They are a significant source of employment and income in rural settings. In addition, the activities created around the energy industry itself represent a significant source of employment opportunity, thereby also contributing to local development.

Beside the level of development, one has to differentiate the various energy sources and fuels when considering economic productivity aspects (Stern 2010). In other words, energy carriers differ in terms of attributes and adequacy for given tasks. Electricity is commonly referred to as the highest quality energy vector, whereas on the other side of the scale biomass is less versatile. Exergy is one measure of such quality and gives an indication of the useful work that can be derived. It denotes the ability of energy to perform work.

Considerations regarding quality are relevant since the productivity that can be obtained from different sources varies. Cleveland et al. (2000) refer to energy quality as 'the relative economic usefulness per heat equivalent of different fuels'. In short, the type (or quality) of energy matters when considering energy for productive uses. An additional important consideration is the cost of making specific energy services available, which is to some extent related to the natural resource endowments in the country.

It is acknowledged that modern energy has the potential to improve the quality of life and increase convenience, but it is the productive attributes of energy use that increase income and provide broad development benefits. It also has a catalyst effect in that energy for productive uses does not merely provide narrow direct benefits that the energy services provide but they triggers, or have the potential to trigger, a leverage effect in terms of development benefits.

Furthermore, since an additional income stream is generated, the financing sustainability of any intervention to promote energy access is improved. In other words, being able to listen to the news on the radio surely provides developmental benefits, but being able to generate income from a small business activity improves livelihood and allows the household members to emancipate.

Even for activities not necessarily requiring energy, such as manufacturing of leather goods, wood carving, weaving, a small amount of energy can markedly improve productivity by extending the working day or enable partial mechanization. A number of analysts (e.g. Lamech & O'Sullivan 2002; Martinot et al. 2002) have identified productive uses of energy. They can be classified as follows:

Table 8-1: **Categories of selected productive uses of energy**

Sector	Service
Formal	Transform raw material into final products, e.g. plastics, cement, glass, metals, agro-processing and forestry operations
	Drive motors for manufacturing, e.g. textiles and garments, canning, bottling, and printing
	Operate essential business infrastructure, such as communications, lighting, and office equipment
Farm	Mechanize irrigation and crop and animal husbandry
Transport	Mechanize transport service
Household production and the rural non-farm sector	More convenient or controlled heat for food preparation and food preservation
	Better lighting, thereby extending the working day
	Use of mechanized equipment to prepare food for sale and for fabrication of tools for small-scale manufacture
	Use of sewing machines
	Use of communications technology to help integrate cottage industries with regional and national markets

Source: adapted from Lamech & O'Sullivan (2002)

Precedents in evaluating the effect of energy on productivity exist in the literature. For instance, while focusing on energy productivity specifically, Enflo et al. (2009) have demonstrated the positive impact of electricity in Swedish industry from 1930 to 1990. Warr et al. (2010) apply exergy analysis of national economies (UK, USA, Austria, and Japan) to assess the state of technology of energy conversion devices and systems. They find a dramatic alteration of the energy system structure and note common characteristics of the transition process that include a rapid growth in exergy consumption and shift from biomass to fossil fuel powered systems. More specifically, their analysis sheds light on the energy transition whereby there is a shift from muscle work to low temperature heat in the early phase, followed by a period dominated by medium and high temperature systems before a swing to a dominance of electricity-based devices.

Marcotullio and Schulz (2007) compare energy transitions in industrialised and developing countries. They reveal that the developing world experiences energy-related transitions at a lower level of income, and with faster rate of change in conditions over time. They also argue that, while the sequence of energy source substitution (from fuel wood and biomass to coal, to crude oil and natural gas, and then nuclear energy and modern renewables) is commonly used to map the energy transition and economic development, there is reason to believe that developing countries are experiencing this transition in a different manner.

It is in line with the argument of other authors that, looking at household energy, instead of a sequential substitution of energy sources, multiple fuel strategies seem to be most commonly the case (Masera, Saatkamp & Kammen 2000). On a similar vein, Howells et al. (2010) analyze the drivers of energy transition, from traditional use of biomass fuel by low income rural consumers and micro-producers, and their respective failures. They find that those failures, if not addressed, could tend to retard the uptake of new fuels and the potential economic growth gained through the energy transition.

Undergoing the industrialization process at a later point in time has the advantage of benefiting from the experience and thereby possibly leapfrogging to more advanced and efficient technologies (Goldemberg 1998). More generally, national economies expand in a different context (e.g. ease of transmission of goods, services, information and knowledge) nowadays compared to decades ago (Marcotullio & Schulz 2007).

There is growing awareness among policy makers, academics and development organizations of the high potential to induce socio-economic development and poverty reduction through the promotion of energy access for productive uses in the developing world. However, there are also concerns about the lack of unambiguous evidence that can help specify the processes that need to occur for this potential to be realized.

Therefore, there is scope for further research to explore the key channels through which increased energy access may enable agents in the economy to trigger pro-poor economic growth. It could be done by linking a theoretical framework with case studies from the existing literature in engineering and development economics. This may well lead to highlighting some of the preconditions and coordination efforts that likely need to exist for the expected developmental outcome of energy-related interventions to unfold.

8.2. Measuring energy poverty

There is significant scope on a number of fronts to further the work on measuring energy poverty presented in this dissertation.

8.2.1. Improving the information base

The challenge of providing universal access to modern energy is daunting yet not insurmountable. The progress achieved in reducing energy poverty over the last few years is encouraging. However, it falls far short of what is needed to adequately address the issue, particularly in specific regions. Ambitious and dedicated action requires international, regional and national political commitment that goes beyond abstraction and sets out targets and associated benchmarks (Bazilian, Nussbaumer, Cabraal, et al. 2010).

The field of work related to the promotion of access the modern energy access is characterized by data paucity. Also, the existing data is often scattered and difficult to access. A reliable and comprehensive information base is however required to set targets and monitor outcomes, to design strategies and policies, to make evidence-based decisions, to invest based on objective data, as well as to enable citizens to make informed choices. Quality quantitative information allows for detailed analysis which underpins the development of programmes, projects, and policies. Also, a robust measuring and reporting framework is the foundation for global monitoring of progress towards internationally proclaimed objectives, such as the Millennium Development Goals. A broadening and strengthening of the information base, alongside efforts to improve its accessibility to a broad audience, are required to ensure effectiveness and to underpin delivery.

Despite the growing number of initiatives geared towards promoting energy access for the poor, there is no one-stop shop platform that facilitates the access of various stakeholders to the wealth of information that is currently being generated, and required for various purposes, with regard to energy poverty. Managing and disseminating the existing knowledge is also an opportunity to explore needs that are not being addressed to date.

A first step to help shed light on the issue of data related to energy poverty would be to carry out a comprehensive inventory of the information available from various sources. A thorough repertory would bring clarity in terms of the type of data available, sources, scope, limitations, etc. A second step would be to develop a repository of the information available to increase the accessibility and comparability of the data.

This effort will require, and significantly benefit from, strategic partners. Those could include, but are not limited to, institutions collecting and owning relevant data (e.g. IEA, WHO, DHS, regional institutions, UNDP, WB, IIASA, US DOE). Noteworthy is to mention that some data are proprietary.

8.2.2. Assessment of capacity at national level to measure and report on energy poverty

There is broad recognition that the country capacity to measure progress towards core development outcomes is instrumental to the success of poverty reduction efforts at national level. Also, a robust measuring and reporting framework is the foundation for global monitoring of progress towards internationally proclaimed objectives, such as the Millennium Development Goals. In addition, at global level, poor quality statistics limit cross-country analysis and undermine efforts to implement global or regional programmes.

Laying the foundation for establishing regular measurement and reporting on energy poverty at national level would represent an important element of the efforts to make access to modern energy services universal. To this end, adequate national statistical capacity is paramount to promoting sustainable development.

Good quality statistical data are a prerequisite to managing for results. With this in mind, evaluating the current capacity and potential gaps and barriers with regard to measuring and reporting on energy poverty at national level in a methodical fashion would be most valuable. Further research could assist in developing a better understanding of the current status and future needs. It would also assess the needs for a central repository of quantitative information on energy poverty at regional/global level.

The international community can play an active role in building capacity and providing resources to increase the quality and quantity of data. Improving the information base is an enormous task and one that will take years. Systematically monitoring progress on energy access will require a cooperative and agreed methodology.

8.2.3. Capturing the gender dimension

The gender issue with regard to energy poverty is commonly overlooked, or treated superficially. The lack of access to modern energy services bares a heavy toll on the poor, and disproportionately on women.

Current tools to quantify energy poverty largely fail to capture the gender dimension. Indeed, available methodologies are helpful to evaluate access to energy, from various perspectives. However, the access to energy might not differ significantly between men and women. What is different are the impacts of the lack of access to modern energy services, whose burden mainly fall on women[141].

Appropriate quantification tools are required to adequately deal with the issue of gender in the context of energy poverty alleviation. Therefore, there is a need to develop and test methodologies to capture and quantify the gender dimension.

8.3. Drawing lessons learnt from past interventions to promote energy access

There is significantly increasing global attention on the issue of energy poverty. This is evident for instance in the recent prioritisation of energy access and electrification given by the United Nations Secretary-General and the launch of various related multi-stakeholder partnerships. While the exact ongoing role of the international community is still being discussed and refined, there is a need to ensure robust analytical information is available to decision-makers.

To that end, it would be valuable to examine the numerous ongoing or past activities at the national or local level aimed at expanding access to energy services in developing countries to serve as precedent for future action. There exists a rich data set of policies, targets, regulations, and financial mechanisms. Assessing various interventions would allow presenting a set of specific insights for future policy design and implementation. Characteristics of best-practice could be derived. It is essential to build on this existing material to ensure that the efforts of the international community are well focused and deeply rooted in national and local conditions and needs.

8.4. Governance for energy poverty

There appears to be an emerging consensus on the diversity and difficult nature of the key energy issues, and the requirement to look at them in a holistic manner. This consensus should be considered an opportunity for leadership. The complexity of energy policy does not allow for simple solutions, governance, cooperation, or regulation. Energy policy attempts to simultaneously optimize a number of objective functions under numerous constraints that are non-linear, and uncertain. Some of the functions to be addressed include notably climate change (and environmental conservation more widely), energy security, energy prices and costs (both as a concern of business and residential consumers), and energy access.

The world is facing an energy crisis that is “taking shape before our eyes” (ElBaradei 2008) with increasing environmental and economic challenges and population pressures in many parts of the world. Therefore, strong institutions and governance structures will be crucial to effectively deal with the enormous task of tackling energy poverty. Correspondingly, the current governance framework will need to make significant adjustments to accommodate the changes that are on-going, as well as those forthcoming in the political, and economic landscape (WEF 2010), changes, whose significance and implications are yet to be fully grasped.

Energy policy is primarily conducted at national and regional levels, and very rarely in international fora. The recent recognition of the interconnectedness of many aspects related to energy policy from social and economic development to climate change to security issues creates a useful foundation for such a discussion to re-emerge. Energy is at the heart of social and economic development. It helps

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[141] There is a wide literature qualitatively describing this effect (Farhar 2000; Karekezi, Banda & Kithyoma 2002; Batliwala & Reddy 2003; Wamukonya 2004; Skutsch 2005; FAO 2006; Oparaocha & Dutta 2011; Parikh 2011).

underpin democracy and equity. It allows reading in the dark, to stay warm in our homes, and to make business. Access to clean energy and related services create the foundations for meeting the Millennium Development Goals.

Whilst energy governance in general has received significant attention in the literature, governance to deal with energy poverty deserves additional attention. It would be important to examine whether the current institutional framework, from the global to the regional to the sub-national, is effective in addressing energy poverty.

9. Overall Conclusion

In this Thesis, several analytical contributions are presented with regard to the nexus energy-poverty-development. Analytical proposals are offered on how to understand the issue of energy poverty, i.e. lack of access to affordable and reliable modern energy services, as well as on the critical assessment of particular instruments to address it, with the objective of providing insights of relevance for policy formulation and for the development of appropriate measures. They consist of applied research as well as methodological development. The research presented herein has been influenced and informed by a range of schools of thoughts. The theoretical inspiration stems from various fields, notably ecological economics to science for policy.

Energy is central to life. Food is endosomatic energy, and.exosomatic energy is at the heart of social and economic development. An adequate supply of energy is necessary for a satisfactory and flourishing human life. The ability of a physical system to do work on another physical system is what is referred to in this Thesis with the notion of energy. The energy flows needed to sustain life of living organisms in terms of food and fodder are not considered in the analyses presented in this Thesis, although recognised as vital.

Energy poverty is a central concept in this Thesis. The services that most people in industrialised countries take from granted – adequate lighting, low-polluting heating and cooking energy, telecommunication and entertainment, motive power – are out of reach to large parts of the world's population. A lack of access to affordable and reliable energy services represents a key obstacle to human, social, and economic development and the achievement of the Millennium Development Goals. As unacceptable and unsustainable as it is, widespread energy poverty represents a stark reality which must be dealt alongside other pressing global issues.

The series of analyses presented in this Thesis focus on the nexus between energy and socio-economic development. They provide contrasting and complementary perspectives around the issue at hand.

The research presented herein contributes to improving the understating of the specifics with regard to the interlinkages between energy and various developmental aspects. To this end, the correlation between different dimensions of energy and the elements characterising the MDGs is articulated using statistical tools. The analysis confirms and reaffirms the generally positive correlation between access to modern energy and socio-economic development. Whilst intuitive, such a relationship had not been quantified and closely analysed in the scientific literature thus far. I provide a perspective on a number of often employed assumptions about the correlation between energy and development, and challenge claims of the universally positive benefits to specific development priorities of access to energy. Indeed, the strength of the correlation varies considerably among the various dimensions. Based on this analysis, I conclude that measures taken to improve access to modern energy services might be particularly beneficial with regard to issues such as drinking water, hunger, and poverty notably, are less so for other dimensions.

Energy poverty is acute in some parts of the world, with billions of people relying primarily on traditional biomass for heating and cooking purposes. Yet, and despite the significant efforts by local institutions and governments, utilities and international organisations, the absolute number of energy poor is expected to rise in coming decades in the absence of additional dedicated action. History has shown, however, that significant progress can be achieved with regard to improving energy access in a short timeframe. Remarkable improvements occurred rapidly in several Asian countries (e.g. Vietnam), South Africa and Brazil in the recent past.

Effective measures and policies to expand modern energy access need to be grounded in a robust information-base. This Thesis reports on the development and application of a novel methodology – the Multidimensional Energy Poverty Index (MEPI) – to measure energy poverty at various levels. Recognising the multidimensional nature of energy poverty, I draw from the field of multi-criteria analysis to develop this innovative tool. It contributes to the field by offering a metric which addresses some of the shortcomings of existing instruments. Whereas most existing indicators and composite indices focus on assessing the access to energy, or the degree of development related to energy, this tool focuses on the deprivation of access to modern energy services. It captures both the incidence and intensity of energy poverty. It can be used for comparative purposes and to track progress towards targets. The additional advantage of this index compared to other tools is that it allows for detailed analysis and disaggregation. Due to the nature of the data (i.e. micro-data based on household surveys), characteristics others than those related to energy poverty are available for each data point. This specific feature permits ancillary analysis by sub-groups of a given population (e.g. by income class). Experience applying this methodology has demonstrated that macro statistics, for instance nation-wide indices, mask significant disparities at sub-group level. The MEPI contributes to the field by providing detailed evidence-based insights of high relevance to the development and implementation of interventions to alleviate energy poverty.

The recent succession of crises has set back some development progress. The international community needs to adjust swiftly to the new circumstances and provide advice and assistance that is resilient and long-lasting, and creates an environment that is conducive to enhancing endogenous development. Current initiatives to eradicate energy poverty are insufficient in scale and scope, and attempting to address the issue in the same incremental fashion as in the past is clearly inappropriate. Today, there is no technical barrier to providing the billions of energy poor with modern, safe, reliable and affordable energy services. It is our duty to deal with the aspiration of countries to move towards modern economies, and energy is paramount to such transformation.

Fortunately, the issue of energy access is receiving greater and greater attention. As an illustrative example, 2012 has been declared by the General Assembly, the main deliberative, policymaking and representative organ of the United Nations, as the *International Year of Sustainable Energy for All*. It is crucial to capitalise on this momentum, as energy is central to facing many of today's key development challenges. Addressing the issue of energy poverty in a comprehensive manner would have enormous multiple benefits (e.g. health, education, gender equality).

Against this background, and to provide a high-level perspective, together with other analysts we have outlined several simple, transparent scenarios for the power sector in sub-Saharan Africa. They employ a simplified methodology to provide a sense of scale of the growth challenges inherent in working towards universal access to electricity services, an objective promulgated by the international community. Understanding the immense scale of the endeavour is necessary to provide a context for, and help guide policy-making. Most projections from international organisations, regional entities, national governments, and power companies foresee growth rates in generating capacity on the order of 6-8% annually – in line with GDP forecasts. While these are dramatic increases over historical rates, and would result in installed capacities of about three times current levels in just two decades, they are insufficient to meet even modest definitions of universal access. This research presents several easily-replicated scenarios that demonstrate the need for at least ten times more installed capacity than today by 2030 (implying sustained average annual growth rates of around 13%). Some kind of 'jump-start' is likely required to move the growth pathway onto this trajectory. The exercise also provided some clarity on several key analytical assumptions that drive power system planning, such as growth rates and mid-term access goals.

To further improve the understanding of the implications of reaching universal energy access within the next two decades, the thesis reports on a critical review of cost estimates related to promoting energy access. Considering some of the gaps identified by existing methodologies, an alternative estimate is provided based on full levelised costs as a means of capturing dimensions absent from other analyses. The conclusion reached is that the total cost of reaching universal access to modern energy services might be significantly higher than indicated by the published studies. With this work, the sensitivity of the estimates to the underlying assumptions is underlined.

Looking into the current flows represents the natural following step. The research provides an updated and refined estimate of macro financial flows to the energy (power) sector in developing countries using several data sets and analytical techniques. The results are primarily 'high-level' aggregates which provide a sense of scale. The comparison is then made between those flows and investment needs. It shows that the current flows are, as a minimum, a factor of five less than that required for universal household access to electricity. Data paucity remains a significant obstacle to further, more refined analysis. This contribution is presented to improve understanding of the 'decision space' of energy poverty and to help inform policy design.

While much remains to be done, and a significant share of the world's population still lacks access to modern energy, history has shown that progress in this regard can be both swift and wide-ranging. Providing that adequate incentives and conditions are in place, the investments required to promote energy access can unfold, bringing about a number of associated developmental benefits. Past successes should serve as encouraging lessons to address the issue of energy access in the regions of the world where it remains a significant barrier to development. There exist a number of relevant financial and policy mechanisms in the realm of energy for sustainable development. One of those stems from international efforts to curb greenhouse gas emissions, namely the Clean Development Mechanisms (CDM).

The CDM seems to have been successful to some extent in contributing to the development of a global carbon market, allowing for temporal and spatial flexibility in achieving emission reduction targets. Yet, its role in assisting developing countries in their effort to promote sustainable development is being questioned. Several actions have taken place intending to remedy to some of those shortcomings. I applied a multi-criteria framework with a particular emphasis on the respect of the principle of incommensurability of the different indicators to systematically compare projects with special attributes (and label) with ordinary ones. Since labelled Certified Emission Reductions, the emissions unit issued by the CDM, are likely to be more costly than those delivered by ordinary CDM activities, it is legitimate to evaluate whether their contribution in terms of sustainable development differs from non-labelled projects. My analysis suggests that, based on the sample of projects evaluated, the sustainable development profile of premium CDM projects tends to be comparable or slightly more ample than similar ordinary projects. Labelled projects do not, however, drastically outperform non-labelled ones. The distinction between projects might very well be within the range of uncertainty intrinsic to such assessment. The contribution of labelled projects to social sustainable development tends to outdo comparable ordinary activities, whereas the contrary holds for economic criteria of sustainable development. Considering that the CDM is at best carbon-neutral, its contribution to sustainable development is critical. Since the CDM is a market-based mechanism, it is likely to be driven by factors others than the contribution to sustainable development in the host-country since those are not marketed. Means to differentiate the quality of the projects, such as labels, therefore provide valuable signals to investors, project developers, and potential certificates buyers, provided that such labels are credible.

This Thesis also outlines areas of further work, for instance related to the productive uses of energy. Once basic needs are fulfilled, electricity, modern fuels and other energy services represent an important factor to improve productivity and generate income. Possible productive uses for the poor that can be enhanced through the provision of adequate energy services include improved agricultural production (e.g. water pumping for irrigation, mechanized tilling) and processing. Yet the concept of energy for productive uses receives little attention in the academic literature and deserves additional critical scrutiny to provide a sound basis for project and programme development. Beside this, there is significant scope for additional work related to measuring energy poverty. Indeed, current analysis suffers from data paucity. Areas where additional work is needed include, *inter alia*, improving the information base by gathering and making accessible the information which is currently scattered. Also, adequately capturing the gender dimension into quantitative analysis on energy poverty would be of great value-added. Moreover, it would be most valuable to examine the myriad of interventions to promote energy access and draw in a systematic fashion characteristics of best practices. Making the most of the rich dataset of policies, regulations, financial mechanisms and the like is critical in an effort to scale up action with regard to energy poverty. Finally, the governance and institutional framework on energy poverty deserves further work. The diversity and complex nature of energy access, combined with the magnitude of the challenge at hand, do not allow for simple solutions. Strong institutions will therefore be required to effectively deal with the enormous task of tackling energy poverty. Drawing from analytical work in the field of climate change, notably with regard to the concept of regime complex, could inform further analysis of the governance framework.

Overall, this Thesis makes a contribution to the field by presenting various perspectives on the multifaceted, complex relationship between energy, poverty and development. The different analytical pieces form a coherent ensemble addressing a number of analytical gaps, thereby providing evidence-based research with the objective of informing dedicated interventions in the realm of energy poverty alleviation.

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