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4

Sustainable policy for energy, land and natural resources

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Contents

Abstract

This thesis consists of four papers which are related to critical natural resource issues from a developing and emerging country perspective. All four papers demonstrate the importance of financial incentives in driving behaviour and investments. Two of the papers apply cost-benefit analysis to complex decisions in the energy and land use sector and two papers model the behaviour of agricultural households.

Determining an optimal strategy for energy investment in Kazakhstan
We analyse energy policy options facing the Kazakhstan government which is seeking to diversify and deliver sustainable development. We use cost-benefit analysis informed by expert testimony to support critical decision-making over the necessary $67 billion in electricity investments to 2050 that can simultaneously contribute to a sustainable economy. The results indicate that for commercial, economic and sustainability reasons policymakers should switch from further investments in coal-based electricity generation to a focus on investments that harness gas and hydropower.

Fuelwood scarcity, energy substitution, and rural livelihoods in Namibia
We seek to improve understanding of the impact of rural energy demand on standing forests. Specifically, we analyse the energy profile of rural households in Namibia, with a focus on fuelwood demand from open-access forests and energy alternatives such as cow dung and open-market fuelwood purchases. The results show that households are largely inelastic in their fuelwood demand, and respond to fuelwood scarcity by reducing energy consumption just slightly more than by increasing labour input to collection, with limited shift to available substitutes. Policy-makers in semi-arid countries should be alert to the potential for predicted population growth to increase fuelwood collection, even in the face of apparent scarcity and substitutes, which in turn risks degrading the integrity and extent of the forest.

Economic Efficiency and Incentives for Change within Namibia's Community Wildlife Use Initiatives
We appraise the economic and financial viability of five community wildlife conservation and utilization initiatives, or conservancies, on communal land in Namibia. For each conservancy, we examine financial profitability, returns on investment and economic efficiency, as well as private returns to project investment made by all stakeholders – community, donor and government. The results illustrate that conservancies are economically efficient, profitable and able to contribute positively to national income and the development process. Crucially, conservancies provide decent financial returns for communities, including income from wildlife use. Conservancies also provide a channel for the capture of international donor grants (reflecting global wildlife non-use values) as income, further strengthening financial returns for communities.

Formal microlending and adverse (or non-existent) selection: a case study of shrimp farmers in Bangladesh
We study the commercial activities and incentives for shrimp farmers in Bangladesh. Shrimp farmers are rural, poor, work entirely in the informal economy, and practice a form of mono-culture. The limited credit access of these farmers is rightly seen as a weakness. The results show that all farmers over-utilise labour to reduce the need for working capital and that informal lenders – with their closer ties to the individual farmers – remain more successful than formal lenders in identifying those smallholder farmers most likely to use the borrowed funds successfully. Informal lenders have an information advantage that formal microlenders lack: the latter need to find routes to access this information for formal microcredit schemes to succeed.

Keywords: Environmental economics, natural resources, energy, climate, microcredit, poverty, sustainability, cost-benefit analysis, agriculture

JEL Classification**:** C81, D70, O13, Q01, Q23, Q48, Q56

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Sammanfattning

Denna avhandling består av fyra papers som behandlar avgörande naturresursfrågor utifrån ett utvecklings- och transitionslandsperspektiv. Samtliga fyra papers visar betydelsen av ekonomiska incitament för att påverka beteenden och stimulera investeringar. Två av dessa papers använder sig av kostnads-nyttoanalys vid komplexa beslut inom energi och markanvändning, medan två papers beskriver beteendet hos jordbrukarhushåll.

Att fastställa en optimal strategi för energiinvesteringar i Kazakstan

Vi analyserar de energipolitiska alternativ som Kazakstans regering – vilken strävar efter diversifiering och att skapa en hållbar utveckling – har att ta ställning till. Vi använder oss av en kostnads-nyttoanalys som utnyttjar expertutlåtanden i syfte att understödja avgörande beslut kring de nödvändiga elektricitetsinvesteringarna på 67 miljarder dollar fram till 2050, som samtidigt kan bidra till en hållbar ekonomi. Resultatet indikeran att beslutsfattare, av kommersiella, ekonomiska och hållbarhetsskäl, bör växla om från ytterligare investeringar i kolkraft till att fokusera på investeringar inriktade på gas och vattenkraft.

Brist på brännved, energisubstitution, och försörjningsmöjligheter på landsbygden i Namibia

Vi strävar efter att öka förståelsen av hur energiefterfrågan på landsbygden påverkar skogarna. Specifikt analyserar vi energiprofilen hos hushåll på landsbygden i Namibia, med fokus på efterfrågan på brännved från allmänt tillgängliga skogar och energialternativ såsom kospillning och brännved köpt på den öppna marknaden. Resultaten visar att hushållen har en i stort sett oelastisk efterfrågan på brännved och reagerar på brist på densamma genom att minska energiförbrukningen endast något mer än man ökar arbetsinsatsen för insamlingen, och att övergången till tillgängliga substitut är begränsad. Beslutsfattare i semiarida länder bör vara uppmärksamma på att den förväntade framtida befolkningstillväxten kan leda till ökad brännvedsinsamling, även i händelse av uppenbar brist och substitut, vilket i sin tur riskerar att försämra skogens skick och minska dess omfattning.

Ekonomisk effektivitet och incitament för förändring inom viltvårdsinitiativ i Namibia

Vi bedömer den ekonomiska och finansiella bärkraften hos fem viltvårds- och användningsinitiativ som drivs av byasamfälleigheter i Namibia. För vart och ett av dessa viltvårdsprojekt undersöker vi privatekonomisk lönsamhet, avkastning på investeringar och samhällsekonomisk effektivitet, samt privatekonomisk avkastning på de projektinvesteringar som gjorts av alla intressenter – lokalsamhället, biståndsgivarna och regeringen. Resultatet visar att viltvård är ekonomiskt effektivt, lönsamt och kan bidra positivt till nationalinkomsten och utvecklingsprocessen. Framför allt ger viltvård god privatekonomisk avkastning för lokalsamhällen, inklusive intäkter från viltanvändning. Viltvårdsprojekt gör även att man öppnar upp en kanal för att fånga upp internationellt bistånd (som återspeglar globala icke-användarvärden förknippade med viltet), vilket ytterligare stärker den privatekonomiska avkastningen för lokalsamhällena.

Formella mikrolån och negativt (eller obefintligt) urval: en fallstudie av räkodlare i Bangladesh

Vi studerar kommersiell verksamhet och incitament för räkodlare i Bangladesh. Räkodlare bor på landsbygden, är fattiga, arbetar uteslutande inom den informella ekonomin och utövar en form av monokultur. Dessa räkodlares begränsade kreditillgång ses med rätta som en nackdel för dem. Resultaten visar att samtliga odlare överutnyttjar arbetskraft för att minska behovet av rörelsekapital, och att informella långivare – med sina närmare band till de enskilda odlarna – i större utsträckning än formella långivare lyckas identifiera vilka av dessa småskaliga odlare som har störst chans att använda de lånade medlen på ett framgångsrikt sätt. De informella långivarna har ett informationsövertag i förhållande till de formella mikrolångivarna: de senare behöver hitta vägar fram till denna information för att de formella mikrokreditprogrammen ska kunna lyckas.

Nyckelord: Miljöekonomi, naturresurser, energi, klimat, mikrokrediter, fattigdom, hållbarhet, kostnads-nyttoanalys, jordbruk
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A special acknowledgement goes to Jon Barnes who sadly passed on in 2014. Jon and I have been jointly authoring journal articles, newspaper columns and research papers for over 15 years. Jon personally spear-headed the integration of rigorous environmental economics into the sustainability policy arena across southern Africa, and trained many of the current generation of young Namibian economists. A pleasure to work with, travel with and learn from, and a great personal loss too.

Second, my supervisors. Thomas Sterner and Jesper Stage have doubtless speculated many times on where I was and whether I would ever finalise this thesis. Being an Industridoktorand brings added and mysterious stresses to the supervisor-student relationship. Outside of the PhD work, my day-job has taken me to over seventy countries, often at short notice and for weeks at a time, forcing my supervisors' questions in which manner of corporate whirlpool I was furiously paddling at any time. Thomas and Jesper in equal part inspired and stretched my work, while all the time endorsing the direction of my progress.

I am thrilled to report that during my travel interactions with academics and university departments around the world, Gothenburg University has a name which is recognised, resonates as a quality institution, and has helped me stand a little taller, feel a little smarter. Furthermore, thanks to my introduction to the delicate industrial art of surströmming in Ulvon, I have an unrivalled ability to share Swedish culture with the world.

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One of the considerable advantages in working while studying is the ability to meet a wide range of people and work “at the coal-face” of economic development. Indeed, I have greatly benefitted from the opportunities afforded to engage in projects and programs that have proved truly game-changing for global economic development. Much of the work has been more procedural than coal face – but thankfully never green-wash. But the client is always right! Nonetheless, always learning, and often as the ‘lone wolf’ economist on these projects, I have had the opportunity to learn throughout from my colleagues on these projects, working alongside anthropologists, agriculturalists, donors, engineers of all types – from civil, oil reservoir, nuclear to process, entrepreneurs, farmers, policy-makers.

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Sixth, the Department of Economics at Gothenburg University. I have worked alongside, with and plotted furiously with colleagues from Gothenburg University for 18 years, ever since I served as driver for Jesper and Gunnar Köhlin on official duties in the north of Namibia. In the past ten years I have visited the Department many times for meetings, learning and seminar participation. As an Industridoktorand, I have had less opportunity than I would have liked to meet, debate and learn from the other participants on the PhD programmes hosted by our Department. Special thanks for the guidance provided by Subhrendu Pattanayak as a discussant in seminars.

Seventh, I must credit cycling. Not only is cycling a crucial part of staying fit, clearing one's head and actively connecting with sustainability, it also teaches us about life and the consequences of taking risks. I was probably ruminating deeply on these risks in April 2012 with a freshly broken hip in bed at home in London, when I hatched a plan with Thomas and Jesper to pursue this thesis. I'm not the only one who wonders whether it was the morphine talking. The importance of this line item is to align with metaphors around getting back on the bike – which I have done – and seeing silver linings in each dark cloud.

Last, yet most importantly, my family. Claire, Rufus, Daisy and Megan deserve my deepest thanks for being my rocks, understanding of the need to invest time in this thesis and PhD study, and knowing when to drag me back into the real world. #IRL as the kids say. Claire has patiently supported, inspired and believed in me, allowing me to carve weekends and evenings out of our time together to work on and finalise this thesis, along with my irregular trips to Sweden. Although the MacGregor family are now doubtless wondering "whatever next?!".

Gothenburg, December 2017

James MacGregor

Introduction

This thesis focuses on the challenges individuals and policymakers face in developing and emerging countries when making decisions on energy, land use and natural resources which aim to be simultaneously economically sound and sustainable. The four papers in this thesis highlight the market failures driving a disconnect between achieving sustainability goals and stakeholders' short- and long-term financial incentives. The implication of this study is that, by identifying and addressing these market failures, the sustainability goals and financial incentives can be realigned to result in more efficient behaviour and allocation of resources.

The reason for this misalignment of incentives is that, when markets function poorly, prices may fail to provide useful signals and may also vary among agents. In addition, some markets, such as those for key environmental services and benefits, do not function at all. These market failures lead to poor decisions being taken owing to misaligned incentives facing not only individuals and households in the short term, but also policymakers making decisions on investments for the long term.

Sustainability goals and concerns risk being sidelined when markets fail. Therefore, when dual environment–development goals are sought, identifying potential and actual market failures is vital. Indeed, evidence from developing and emerging countries now shows that it is possible to identify multiple overlapping market failures (Borot et al., 2009; Groom and Palmer, 2014). The papers in this thesis illustrate how these failures happen. For example, subsistence households face inelastic demand curves for energy without recourse to fuelwood markets (which imperils local forests); community conservancies face missing markets for non-use values for wildlife (which risks leading to biodiversity loss); microcredit agencies miss vital economic performance data on their customers (which results in selection biased in favour of higher-risk farmers); and policymakers maintain low prices for energy for political reasons (which reduces incentives to seek sustainable alternatives). Furthermore, we find common concerns which have emanated from across the wide range of agents, business models and economic sectors regarding how failed markets impact sustainability.

The economic and sustainability benefit to incorporating an environmental economics approach when making critical decisions over investment and policy is both long-term and well-established (Bromley, 1995; Pearce et al., 1989). For policymakers, considerable help is at hand to support diagnosis of the relevant issues, analysis of underlying causes and implementation of remedial action, as well as integration of such insights into policy and investment decisions (e.g. HMT, 2003; Smith, 2011; and several valuation databases, e.g. DEFRA, 2015; Environment Canada, 2015). Yet in developing and emerging countries, relevant data to make decisions are often unavailable. The papers collected here seek to contribute to the literature on addressing market failures in developing and emerging economies to enable better decisions with respect to the energy sector (Papers 1 and 2) and land use (Papers 3 and 4).

Access to affordable, clean and reliable energy is enshrined in the United Nations' Sustainable Development Goals (specifically SDG7) for 2030, and has long been a policy goal for most countries. Despite this, half of the world's population remains without access to electricity and many with access suffer an unreliable and costly supply (MacGregor, 2017). Hence, Papers 1 and 2 seek to identify and quantify some of the market failures that burden energy sectors in developing and emerging countries when prices fail to signal outcomes that are simultaneously uneconomical and unsustainable. Incentives facing all stakeholders are further complicated by financial and labour market failures, which result in decisions being taken individually and collectively that are economically inefficient, financially costlier and less environmentally sustainable. As the studies reported in these two papers show, the identified failures in the energy markets require realigning to incentivise households, the private sector and policymakers to take social and environmental externalities into account in their decision-making.

In terms of land, decisions regarding its use customarily weigh short- and long-term investment risks against their alternatives. However, in developing countries, imperfect markets for capital, labour and environmental resources may bias land use decisions against long-term investments (Barbier, 1997) without due consideration for environment-oriented development goals. Other challenges in developing countries frustrating the identification of market failure and efforts to realign incentives include multiple overlapping market failures, incomplete data on economic activity, missing markets and the wide variation in prices facing different agents. Clearly, it is important to identify and address these market failures and to support decision-making to be simultaneously economic and sustainable (Mertz, 2008). This thesis exposes the misalignment of incentives among stakeholders, namely donors, conservancy managers and conservancy households (Paper 3), and farmers, informal lenders and formal microcredit scheme managers (Paper 4).

Two approaches are presented across the four papers. Two of the papers apply cost–benefit analysis (CBA) to complex decisions in the energy and land use sectors (Papers 1 and 3), while the remaining two model the behaviour of agricultural households (Papers 2 and 4).

Summary of papers

Paper 1, *Determining an optimal strategy for energy investment in Kazakhstan* (published in 2017 in *Energy Policy*), analyses the energy policy options facing the Kazakhstan Government which is seeking to diversify its economy and deliver sustainable development. Kazakhstan has expansive coal reserves, and this natural resource asset continues to influence energy decision-making. A looming electricity generation shortfall coupled with ageing infrastructure has made decisions over energy investments a political and economic priority. The analysis employs a broad CBA approach to support decisions on future electricity generation investments.

From a relatively low starting point, the Government of Kazakhstan is seeking to accelerate the integration of sustainability concerns into its governance policies by adopting a bold Vision and making strategic investments to achieve it (GoK, 2012; Ospanova, 2014). In the energy sector, a key policy constraint is the desire to maintain artificially low prices for electricity, owing to protests over tariff escalation across Asia. Compounding this, markets for credit are weak and several environmental values remain unpriced at present. For the energy sector, these market and policy imperfections incentivise short-term household behaviours and long-term policy decisions that are misaligned with sustainability goals.

Following Hammond et al. (1999), Howard (1966) and Spetzler et al. (2016), we apply structured decision-making, using the collective expertise of an interdisciplinary group of stakeholders to identify policy options. Following Creedy et al. (2009) and Kass et al. (2011), these policy options were compared quantitatively using CBA, which integrated official government and private sector data together with estimates elicited from the group of stakeholders.

The results of the analysis indicate that, for electricity generation, Kazakhstan should begin to switch from coal and focus on harnessing the commercial and economic advantages of gas and hydropower. Compared with the current production mix, these options would not only be cheaper, but also have considerably lower emissions and water usage. Given the market and policy imperfections, therefore, public investments should be focused on generating incentives to develop this sector's transformation from business-as-usual. Further challenges persist, however, both in ensuring energy access to remote communities and in guaranteeing affordability throughout the energy network.

In Paper 2, *Fuelwood scarcity, energy substitution, and rural livelihoods in Namibia* (co-authored with Charles Palmer and published in 2009 in *Environment and Development Economics*), we aim to enhance understanding of the profile of energy demand, substitution and costs. Specifically, we analyse energy use by rural households, with a specific focus on demand for fuelwood from open-access forests and demand for energy alternatives such as cow dung and fuelwood purchases on the open market.

We use survey data collected with Namibia's Ministry of Environment and Tourism throughout northern Namibia from in-person interviews about trends in household use of forest resources (Barnes et al., 2005; MacGregor et al., 2007). We also use data from work on compiling forest resource accounts for Namibia (Barnes et al., 2010) as a guide to relative scarcity. We find, in common with most studies in developing countries, that rural agricultural households in this region rely on forests for energy, shelter and livestock grazing (Blackmore and MacGregor, 2011; Clay et al., 2005; Kanji et al., 2005; Vorley et al., 2008, 2009).

We then model households as engaged in agricultural production, off-farm work and energy collection. A household's primary input to fuelwood collection is labour, so its shadow price is defined by the opportunity cost of collection time. It follows that heterogeneous households face different market or shadow prices for fuelwood collection; hence, each household would be making non-separable production and consumption decisions. We follow Sadoulet and De Janvry (1995) and analyse the price band facing rural households for fuelwood – that is, the difference between the prices for market purchases and sales – to ascertain incentives for consumption, production and vending. A market can be considered at risk of failing for a particular household if that household faces a 'price band' with a wide margin, with incentives to choose self-sufficiency if its shadow price for fuelwood collection falls within that margin.

A household model for domestic energy supply and demand is estimated using these data. Heckman two-step estimates (Heckman, 1976, 1979) show that households respond to economic scarcity, as measured by the opportunity costs of collecting fuelwood: their response is to reduce their energy consumption by slightly more than the degree to which they would increase labour input to collection.

Furthermore, we find limited substitution of cow dung for fuelwood as an energy source. These findings are in line with similar studies (Cooke et al., 2008; Jeuland and Pattanayak, 2012; Mekonnen, 1999) in that increased opportunity costs of collecting fuelwood due to increased scarcity do not appear to correlated either with substitution to apparent alternatives such as cow dung, or with increased market purchases of fuelwood. Furthermore, our interpretation is in line with Hyde and Köhlin (2000), indicating that the poorest households may be more responsive than other groups to this fuelwood (economic) scarcity.

Our findings are relevant not only for Namibia, but also for policy concerning forest management in communal lands in other semi-arid countries. Since this paper was published, similar studies have been conducted in a large number of developing countries in Africa and Asia (Akther et al., 2010; Guta, 2014; Makungwa et al., 2013). Some have analysed the shifting market dynamics of agricultural supply chains (Borot et al., 2008; Graffham et al., 2006, 2008; Groom and MacGregor, 2007; Kleih et al., 2007; Legge et al., 2008; MacGregor, 2010a, 2010b, 2010c; MacGregor et al., 2009, 2014), while others have focused on short- and long-term incentives for environmental investment (Chambwera and MacGregor, 2009; Huq and MacGregor, 2009; MacGregor, 2006a, 2009; MacGregor and Vorley, 2006). As predicted in our paper, growing populations in developing countries have been increasing the pressure on forests and their products (Gwavuya et al., 2012; Nepal et al., 2010; Prinsloo et al., 2016; Schaafsma et al., 2012).

In Paper 3, *Economic efficiency and incentives for change within Namibia's community wildlife use initiatives* (co-authored with Jonathan Barnes and Chris Weaver, and published in 2002 in *World Development*), we appraise the economic and financial value of five community wildlife conservation and utilisation initiatives, or conservancies, on communal land in Namibia.

Conservancies aim to provide, simultaneously, positive incentives for conservation of natural resources and improved livelihood opportunities (Naidoo et al., 2011). A critical part of any conservancy's success is ensuring clear incentives are given to members for conservation of the natural resources within its boundaries. Non-use values are not reflected in conservancy members' incentives and are causing the market to fail (Humavindu and Stage, 2015; MacGregor and Hesse, 2013). With the help of donor funding, these values can be captured, but this carries the risk that the incentives based on such values are not integrated or sustainable, and that the community could become dependent on donor funding.

For each conservancy, we examine financial profitability, returns on investment, economic efficiency, and private returns to project investment made by all stakeholders – community, donors and government. Namibia's policy and legislation allows community-based natural resource management (CBNRM) on communal land. Much of the initial focus of CBNRM has been on wildlife (Barnes, 1995; Barrett and Arcese, 1995; Gibson and Marks, 1995; Lewis et al., 1990; Meissner, 1982), which is threatened with displacement by growing rural human populations and illegal use (Barbier, 1992). The CBNRM approach devolves rights over wildlife to local communities and aims to make wildlife conservation part of the rural development process (Barnes et al., 2012; Bond, 2001; Infield, 2001) alongside traditional agriculture and livestock rearing (Hesse and MacGregor, 2006; Letara et al., 2006). In this context, CBNRM initiatives need to be financially attractive for the community, economically efficient for the country, reasonably financially viable for donors and the government and, in the long term, commercially feasible to the private sector. Without these incentives, conservancies and the CBNRM programmes they run will not be sustainable, and will not result in development or conservation.

Following Emerton (2001) and Pearce and Turner (1990), we analyse the financial and economic viability of each conservancy using dynamic cost–benefit models that employ survey data from in-person interviews with conservancy leaders and wildlife use enterprises, coupled with information from individual conservancy management plans. Following Barnes (1994), CEAS (1989), Gittinger (1982), Matambo (1988), and Ministry of Finance and Development Planning (1986), we employ shadow pricing in the economic analyses to account for the range of data challenges in rural areas.

We find conservancies are economically efficient, profitable and able to contribute positively to national income and the development process. Crucially, conservancies generally attract financial returns for communities, including income from wildlife use. They also provide a channel for the capture of international donor grants (reflecting global wildlife non-use values) as income, and generate attractive financial returns for communities.

Donor grants are fertile catalysts for land use change in conservancies. Yet for long-term sustainability conservancies need to prove attractive to the private sector and to ensure there is an exit strategy to avoid dependency witnessed in other economic development programmes. Our results demonstrate that the ability to generate income from tourism is important for overall financial viability for all conservancies. Thus, policy that enables genuine engagement with the private sector is most likely to yield sustainable development outcomes that do not require persistent government and donor investment.

Since this paper was written, the Namibian CBNRM Programme has continued to develop and expand successfully (Hoole and Berkes, 2010; Naidoo et al., 2011). The CBA approach used in this paper has been applied to conservation questions in Namibia and increasingly across southern Africa in the donor, government and business investment arena (Barnes et al., 2008; Chaminuka et al., 2012; Emerton et al., 2005; MacGregor and Hesse, 2013; Reed et al., 2015). The environmental economic approach, using CBA coupled with an understanding of stakeholder views, has proved important in ensuring communities are both investors and partners in the economic development of conservancies, and not mere bystanders (Bandyopadhyay et al., 2009; Kanapaux and Child, 2011; Pienaar et al., 2013; MacGregor, 2006b; MacGregor et al., 2004; Reid et al., 2007, 2008).

In Paper 4, *Formal microlending and adverse (or non-existent) selection: A case study of shrimp farmers in Bangladesh* (co-authored with Camilla Andersson, Erik Holmgren and Jesper Stage, published in 2011 in *Applied Economics*), we study the commercial activities and incentives for shrimp farmers in the informal economy in Bangladesh. Shrimp farmers are rural and poor; they work entirely in the informal economy; and they practise a form of monoculture. These farmers' limited access to credit is justifiably seen as a weakness. Formal microcredit is considered an effective intervention by public agencies and international donors, but the informal private sector provides a greater variety and volume of loans – albeit at higher apparent costs to the borrower.

It has long been noted that limited access to credit is an important constraint on progress in rural areas in many developing countries (Hermes and Lensink, 2007; Hoff and Stiglitz, 1993). Our study found that the credit markets available to shrimp farmers were failing to allocate credit efficiently in ways that maximise farmers' financial and economic growth. In our survey, it is significant that all farmers considered themselves to be credit-constrained. Furthermore, microcredit scheme managers struggled to identify those most likely to repay loans successfully. As a result of these market conditions, short- and long-term incentives for donors and farmers are misaligned not only with their need for working capital, but also with the need for formal microcredit schemes to be profitable.

Using data from an in-person survey, we compare how borrowers in a rural shrimp farming district in Bangladesh are selected by formal microcredit schemes on the one hand, and traditional informal credit sources on the other. We estimate the shadow prices that farmers are willing to pay for additional credit. In doing so we rely on an approach originally developed by Lau and Yotopoulos (1971), which has not been used to compare these two forms of credit before. Following Bhattacharyya et al. (1994), Kumbhakar and Bhattacharyya (1992), Stefanou and Saxena (1988) and Wang et al. (1996), we analyse the data for differences among farmers who obtain formal loans and those who obtain informal credit.

In light of our findings, it is clear that neither formal nor informal credit schemes have succeeded completely, wth all farmers reporting they remain credit-constrained. All farmers also overutilised labour to reduce the need for working capital. Furthermore, our results indicate that borrowers who made exclusive use of formal loans have higher shadow prices for additional credit, and are perceived as worse credit risks than the farmers who also borrowed informally. This suggests that the farmers who only borrowed formally were a worse group of borrowers, on average, than the informal borrowers. This further entails that informal lenders – with their closer ties to the individual farmers – remain more successful in identifying smallholder farmers that are most likely to put the borrowed funds to optimal use.

We find in our data that the informal lenders had an information advantage that formal microlenders lacked. For formal microcredit schemes to succeed, therefore, they need to find routes to access such information. Our findings underline the importance to assess and, where possible, build on existing economic conditions that are conducive to meeting a stated objective, and to exercise due diligence and restraint when considering, as here, supplanting one credit system with another.

Our paper raised and predicted several key issues which continue to hamper the scaling of microcredit and microfinance in the agricultural sector of developing countries. Indeed, since the paper's publication in 2011, microcredit has continued to face challenges to its theoretical underpinnings, to its success in practical implementation (Gueyie et al., 2013; Janda and Zetek, 2014) and to its applicability to agriculture (Meyer, 2013;

Vishwanatha and Eularie, 2017). Furthermore, since informal moneylenders not only remain a dominant financial institution (Ali et al., 2016; Chambwera et al., 2012; Jordan, 2014), but have also not yet been incorporated or integrated into the management plans for donor- and government-sanctioned microcredit enterprises, credit markets remain weak for the majority of the poor (Haldar and Stiglitz, 2016; MacGregor et al., 2016; Rai et al., 2015; Soanes et al., 2017; Véron and Majumdar, 2011).

Concluding remarks

Our findings across these four papers should guide decision-making over land, energy and natural resources so that they may be more sustainable and profitable for all stakeholders. We show how market failure stalks the best intentions of individuals, households, communities and policymakers who strive to comply with demands for sustainability while maximising economic opportunities. Nonetheless, our findings highlight the potential benefit of identifying these market failures and of realigning stakeholders' short- and long-term financial incentives through better policy that is informed by evidence.

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Paper I

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Determining an optimal strategy for energy investment in Kazakhstan

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ABSTRACT

The economy of Kazakhstan is locked into reliance on fossil fuel energy sources. Its government is seeking to diversify and deliver sustainable development. We develop an approach to decision-making to support critical decisions over the necessary $67 billion in electricity investments to 2050 that can simultaneously contribute to a sustainable economy. We apply structured decision-making and cost-benefit analysis, align politically by incorporating the collective expertise of an interdisciplinary group of stakeholders to identify Policy Options, commercial assumptions and externalities, and fill data gaps using technical, economic and environmental data from global sources. Our approach quantifies net present value of these identified Policy Options, explores sensitivities, and suggests alternative investment pathway. Our results indicate policymakers should switch from coal and focus on harnessing the commercial and economic advantages of gas and hydropower for electricity generation. These options would be cheaper and have considerably lower emissions and water usage than the current production mix.

1. Introduction

The Government of Kazakhstan (GoK) is seeking to change its growth trajectory to realise economic growth, energy security and sustainable development, but the country faces three challenges in delivering these three simultaneously. The first is developing an effective strategy to ensure energy security, as the population and economy grow (ADB, 2013). Second, looming domestic electricity generation shortfall from the early 2020s onwards coupled with ageing infrastructure reaching the end of its lifespan and being decommissioned entailing large government investments. Third, is implementing its strategy in light of demand realities and making better decisions. An example is Kazakhstan's electricity generation is based on its abundant reserves of coal and other fossil fuels, rather than on expanding existing and developing new renewable energy sources.

Politically, Kazakhstan has embraced a vision to become one of the world's most environmentally healthy countries, with sustainable energy at its foundation and broad economic development as a key objective. As stated in the Kazakhstan Strategy 2050, the Government's long-term goals include making the country a middle-income nation by 2030; generating half of Kazakhstan's electricity from non-hydrocarbon sources by 2050; increasing the use of alternative fuels; and entering the ranks of the world's top 30 most developed nations by 2050 (GoK, 2012). Furthermore, Kazakhstan's Intended Nationally Determined Contribution commits to an economy-wide target of 15–25% reduction in GHG emissions by 2030 compared with 1990 (GoK, 2015a, 2015b). The Paris Agreement signed by Kazakhstan on 3 August 2016 further commits the nation to larger reductions (UN, 2016). Other recent developments include the Government's Green Energy Concept in 2013 which introduced feed-in tariffs for wind and solar energy, with a target of achieving 3% of energy generation by 2020; the Energy Efficiency 2030 programme which aims to reduce the economy's energy intensity by 25% by 2030; and the Wind Power Development programme which defines such development as a priority direction for the country (IEA, 2014).

Although Kazakhstan has a poor record on some environmental indicators, in respect of others – such as the exploitation of its large oil reserves, high national carbon dioxide emissions, and its high per-capita carbon dioxide emissions (GoK, 2016) – there is a discernible political move towards promoting sustainable policy and investments. To date, political action includes developing carbon taxation as part of a policy shift towards a more sustainable economy (Ospanova, 2014; GoK, 2012), and an Emissions Trading Scheme developed under the Kyoto Protocol (GoK, 2013), although the Scheme was temporarily suspended until 2018 (ICAP, 2016). However, whether these policies will be enough to allow Kazakhstan to meet its growing electricity demand simultaneous with sustainable development, and whether they will represent the cheapest and best economic options for doing so, remain to be explored more fully.

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Looming electricity supply shortfall coupled with ageing infrastructure makes decisions over investment in electricity generation a priority and presents an opportunity to integrate the sustainable development vision in major public investment, attendant policy, incentive mechanisms and public consultation. For public investment purposes, Kazakhstan has solid government finances. Indeed, the political focus on domestic economic indicators, and at this time, the importance of foreign debt sustainability and foreign exchange earnings are secondary to domestic political concerns. Some evidence of this robust fiscus is provided by the country's relatively swift return to economic prosperity compared to other Former Soviet Union countries (NBK, 2016; SWFI, 2016). Lower global prices for Kazakhstan's main exports since 2014 – particularly crude oil, industrial metals and wheat – temporarily imperilled the domestic economy and reduced its international trade with the Eurasian Economic Union by 21% and all countries by 19.9% (NBK, 2016; NBK, 2017; MNE, 2016; MNE, 2017b). However, since late 2016, there are positive indications of prosperity returning, including industrial growth at 3% and inflation stabilised at 6–8%, alongside public sector measures during 2015 including a 5.6% growth in state budget spending to KZT 8.2 trillion and transition to a free-floating exchange rate regime (NBK, 2016; MNE, 2017a).

Tellingly the political will around the Kazakh Government's energy security and sustainable development goals has persisted despite the commodity price crash in 2014 (EBRD, 2016), and even sharpened its focus on the domestic beneficiation of its natural resources and on small- and medium-scale enterprises (Euronews, 2016; Reuters, 2016).

To deliver on its vision and satisfy indicators of a sustainable economy, the GoK will need to make informed decisions that explicitly trade-off economic and the environment. Yet, in Kazakhstan, decision-making over energy policy and investment would improve if there was better information, data and evidence, coupled with an appropriately structured decision framework (ADB, 2013). Furthermore, major investment decisions – such as over electricity generation infrastructure and technologies – are becoming more complicated in light of these fresh political commitments to economic growth, energy security and sustainable development. Clearly there is a need to corral data, evidence and stakeholder views in advance of making the considerable financial investments that are required. It is the fundamental premise of this paper that in order to meet these sustainable development goals and ensure energy security, the investment decisions of the Government of Kazakhstan will require cost-benefit analyses that are both structured and identify, consider and integrate all relevant components.

This paper contributes to the identification and analysis of Kazakhstan's electricity options. This paper adds to the small literature that deals with Kazakhstan's energy security (Miglio et al., 2014), domestic demand management (Sarbassov et al., 2013) and complements the literature on electricity and energy security among Central Asian countries in general (Miglio et al., 2014).

2. Kazakhstan's electricity sector

Kazakhstan gained its independence from the Soviet Union in 1991, at the same time as its Central Asian neighbours – Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. Independence transformed the former Soviet Union (FSU) power monopoly system, and handed responsibility for electricity generation and the national power balance to new national monopolies. Independence triggered recession and a 50% drop in electricity production, which in turn resulted in a lack of funds for operations and maintenance across the power management system, and a critical under-investment in new assets – which persists. Since Independence, the Central Asian economies have focused on isolating and growing their energy systems in a bid to enhance their domestic energy security (IEA, 2014; Acemoglu and Robinson, 2013; Acemoglu and Yared, 2010) with a sharp eye on potentially profitable exports to its neighbours which harbour equally low electricity tariffs (Inogate, 2015). Yet, trade in electricity does occur with its neighbours both owing to seasonal variations and as part of several high-level political cooperation, trade promotion and long-term contracts (Kadrzhanova, 2013). For instance, the Supreme Interstate Council of Kazakhstan and Kyrgyzstan facilitates the trade of 86% of Kyrgyzstan's total annual electricity exports to Kazakhstan alongside most of its dairy and agri-food exports (GoK, 2015a, 2015b). Undoubted efficiency gains could be made from a more integrated and market-based regional electricity network if there were greater coordination between electricity-producing units in the various Central Asian countries (via markets or through joint ownership of multiple units), and if overall production shifted to those parts of the region with the greatest comparative advantages in electricity production. However, such an integrated regional electricity market is unlikely for the near future since it entails the loss of national political control over electricity pricing and electricity availability.

Electricity tariff increases in Kazakhstan have been proposed but shelved after being met with protests from small- and medium-scale enterprises as well as the general population (RFE/RL, 2016a, 2016b). Electricity pricing across Asia is a political hot potato. Several countries have experienced widespread protests over their governments' attempts to increase electricity prices (The Guardian, 2015; RFE/RL, 2016a, 2016b; Paul, 2017). Thus, for the near future, a key political goal for the electricity sectors across Central Asia would be to avoid policies that risk leading to higher electricity prices or to increased uncertainty in supply. Since Independence, residential consumers in Kazakhstan have paid almost double the rates of their industrial counterparts (ANMR, 2010). Yet even for these residential customers, Kazakhstan has some of the lowest electricity prices in the world, owing to subsidies of approximately 60%, and tariffs set and regulated by the ANMR (EBRD, 2010; Nugumanova, 2013). Low prices for electricity explain the concomitantly subdued level of reinvestment by electricity generation companies, the reliance of many manufacturing firms on own electricity production, and the restrained level of access to electricity in remote and rural areas owing to the expense of extending supply networks.

Today, Kazakhstan's electricity sector is split between those elements regarded as a natural monopoly and a liberalised competitive wholesale sector, albeit with retail tariffs still regulated by the Government. Governance is provided by the Agency of Natural Monopolies Regulation (ANMR) which holds authority to determine tariffs and their calculation methodology, but is not empowered to authorise new capacity (GoK, 2005). The other type of entity in Kazakhstan's electricity sector is the Unified Power System, which consists of a deregulated and competitive wholesale market and retail markets.

The main electricity market participants are the national power grid company (the Kazakhstan Electricity Grid Operating Company (KEGOC), which is a joint stock company or JSC), which is responsible for the 24,644-km transmission network; electricity producers with a range of ownership structures, which operate 66 power plants; electricity distribution companies, which operate 29 distribution networking centres; the JSC Kazakhstan Operator of Electric Power and Capacity Market (KOREM), which operates the centralised trading of electrical energy; and the consumers of electricity themselves (EBRD, 2010; KEGOC, 2016a; KOREM, 2016).

Kazakhstan's domestic electricity generation infrastructure has a capacity of 19,200 MW, with an available capacity of 15,765 MW. Over 90 billion kWh of electricity was generated annually since 2013, rising by an average of 4.5% since 2001. Over this period, the significance of exports has shrunk from 8% of total annual electricity generation to less than 5% and imports halved to 3% (Table 1).

Kazakhstan has 3.6% of global coal deposits and one of the largest proven natural gas reserves, at 1900 bcm (Parkhomchik, 2016; IEA, 2011; Rowland, 2016). Coal dominates as an electricity power source accounting for 81.6% of domestic electricity generation (Table 2) and

Table 1
Electricity system by components (billion kWh), 2001–2015.
Sources: ARKS (2014a), BP (2016), IEA (2014), KEGOC (2011, 2016a), KOREM (2016) and MINT (2011)

Components	2001	2003	2005	2007	2009	2011	2013	2015
Generation	53.85	60.47	64.17	72.41	74.33	81.79	91.90	90.80
Consumption	49.18	52.79	57.09	65.30	67.19	76.21	82.78	81.75
Imports	3.44	3.51	3.52	3.38	1.71	2.60	2.10	0.64
Exports	1.64	4.98	3.65	3.31	2.38	1.81	4.40	2.92
Distribution losses	6.47	6.21	6.95	7.19	6.47	6.37	6.82	6.77

Table 2
Electricity generation (billion kWh) by power source, Kazakhstan, 2015.
Source: KOREM (2016).

Power source	Electricity generation (%)	Billion kWh
Coal	81.6	74.09
Hydropower	10.2	9.25
Gas	8.0	7.28
Renewable	0.2	0.18
Total	**100**	**90.8**

serves as fuel input for all but two of the largest ten Thermal Power Plants (Table 3). Hydropower generated from six large-scale hydropower plants (LHPPs) constitutes 10.2% of Kazakhstan's total electricity production (Tables 2 and 4), with lower output from small- and medium-scale hydropower plants (SMHPPs) (Table 5).

The national power system faces challenges, with low operating efficiency, estimated transmission losses of 5–20% owing to poor maintenance (KEGOC, 2011; MINT, 2011; Soros Foundation, 2015), and ageing assets: the average age of TPPs is 45 years; 70% of LHPPs are over 30 years old; and only 5% of SMHPPs currently operate (Domnin, 2016; Liu et al., 2013; MEP RK, 2009). The impact of these inefficiencies is felt most in remote areas: a considerable proportion of the rural population remains unserved, and the degree of reliability in the electricity supply is low even for those who are connected. Kazakhstan has one of the highest energy use per unit of gross domestic product (GDP) across continental Eurasia (World Bank, 2013) and 12% higher than that for the Russian economy (GoK, 2013). Addressing these is critical in order to develop the country towards sustainable development with efficient markets, institutions and policy, but this analysis is beyond the scope of this paper.

Currently, the IEA estimates the level of penetration for energy-efficient technologies is only 50%, providing considerable opportunities for investment in the near future. The paper is limited by the lack of official or published data on the efficiency within the electricity markets and system (IEA, 2016). We expect the efficiency to increase over time, with new investment and in line with the aspirations of Strategy 2050 and Vision 2030.

The Coady et al. (2015) estimates that electricity subsidies cost about $148 billion in 2015. In line with most resource-rich countries and most non-OECD countries, Kazakhstan provides high subsidies on fossil fuels to end consumers. For example, for coal there is a 60% subsidy, which comprises 3% of GDP (Nugumanova, 2013; IEA Energy Subsidy Database, 2016). Indeed, In light of global research that shows the benefits to nations of removing these subsidies, there is compelling evidence this would be potentially beneficial to Kazakhstan's economy, energy market efficiency and climate change compliance (Nugumanova, 2013; Coady et al., 2015).

Table 6 shows that investment in new electricity generation assets by 2020 should bring the total generation capacity to over 130 billion kWh, with planned coal, hydropower, nuclear and wind projects.

Abundant coal reserves result in a competitive cost for inputs to electricity generation, sees coal dominate electricity generation. The future of coal as the dominant fuel source for electricity generation has been challenged by GoK strategies on sustainable development, including to generate half of electricity from non-hydrocarbon sources by 2050 in Kazakhstan Strategy 2050.

Despite considerable reserves, natural gas development is not deemed a priority in Kazakhstan. Partially this may be due to it being ‘associated gas’ produced alongside readily commercialisable crude oil, and primarily used for reinjection to maintain wellhead pressure. Current investments underline this, being focused on powering industry at the Aktobemunaygas complex, the Kumkol oilfield, and the Tengiz oil-to-gas complex. Compounding this is a lack of infrastructure, entailing expense associated not only with building new infrastructure, but also with connecting the widely dispersed population to production centres in the northwest of the country. Further investment is required to replace ageing turbines, storage and processing industry development.

Kazakhstan's total electricity generation capacity from hydropower was officially estimated at 2581 MW in 2015 (KEGOC, 2016a). Only 4% of this comes from SMHPPs, however. The importance of SMHPPs is magnified in rural off-grid locations across Kazakhstan, particularly those areas with sizeable populations or industry. Their importance is also reflected in current projects to revive such plants, including building the medium-sized Kerbulack SMHPP (50 MW in total) on

Table 3
Ten largest thermal power plants by output (billion kWh), Kazakhstan.
Sources: Adapted from ATFBank Research (2011) and WorleyParsons and Acclimatise (2013).

No.	Power plant	Owner	Gene-ration (billion kWh/ year)	Capacity (MW)	Type of fuel	Province	Year commis-sioned	National produc-tion (%)
1	Aksu	Eurasian Resources Group	13.47	2100	Coal	Pavlodar	1968	14.83%
2	Ekibastuz-1	Kazakhmys	10.32	4000	Coal	Pavlodar	1980	11.37%
3	Karaganda-2	Kazakhmys	4.48	2120	Coal	Karaganda	1967	4.93%
4	Ekibastuz-2	Samruk-Energy JSC/ InterRAO UES	4.48	4000	Coal	Pavlodar	1983	4.93%
5	Maek 2–3	Kazatomprom	4.02	630	Gas	Mangystau	1990	4.43%
6	Temirtau	JSC Arcelor Mittal Temirtau	3.00	435	Coal	Karagandy	1934	3.30%
7	Petro-pavlovsk	Access Energo	2.38	336	Coal	North	1961	2.62%
8	Astana TPP	Astana Energy	2.35	400	Coal	Astana	1961	2.59%
9	Karaganda	Karaganda-ElectroCenter	2.25	395	Coal	Karaganda	1967	2.48%
10	Zhambyl	SamrukEnergo	1.35	1230	Fuel oil	Taraz	1968	1.49%

Table 4
Large-scale hydropower plants (> 100 MW) by generation (billion kWh/year), 2012.
(Sources: Adapted from ATFBank Research (2011), MEP RK (2009), KEGOC (2016a) and WorleyParsons and Acclimatise (2013)).

No.	Power plant	Owner	Generation (billion kWh/year)	Capacity (MW)	No. of turbines	River	Year commissioned	National production (%)
1	Bukhtarma	Kazakhstan Electricity Grid Operating Company	2.77	675	9	Irtysh	1960	3.26%
2	Shulbinsk	AES Corporation	1.66	702	6	Irtysh	1987	1.95%
3	Ust-Kamenogorsk	AES Corporation	1.58	339	4	Irtysh	1952	1.86%
4	Moinak	Kazakhstan Electricity Grid Operating Company	1.27	300	2	Sharyn	2011	1.49%
5	Kapchagay	JSC Almaty Power Plants	0.97	364	4	Illy	1970	1.14%
6	Shardara	JSC Shardarin-skaya	0.42	100	2	Syr Darya	1965	0.49%
	Total		**8.67**	**2480**	**27**			10.20%

Table 5
Small hydropower plants (< 100 MW) by region, Kazakhstan.
Sources: Domnin (2016), Liu et al. (2013) and KEGOC (2016a).

No.	Region	No. of plants	Operational	Capacity (MW)
1	Southern Kazakhstan	112	0	0
2	East Kazakhstan	68	1	13.8
3	Zhambyl	72	3	14.9
4	Almaty	8	8	72.1
	Total	**260**	**12**	**100.8**

the Ily River, and other SMHPPs on mountainous rivers with a planned combined power of 100–200 MW (MEP RK, 2009).

Wind potential in Kazakhstan is estimated at 929 billion kWh a year, or 354 GW of installed capacity (UNDP-GEF, 2011), and would need to cover 2% of the country's land (MEP RK, 2009). The commercial viability of wind power generation was demonstrated in a recent study conducted by the United Nations Development Programme and the Global Environment Facility. The study investigated the feasibility of 15 wind farms, wind power generation under the Kazakhstan Wind Power Development Programme, and several joint ventures with local government (EBRD, 2009).

In respect of solar energy production, Kazakhstan's climatic conditions are suitable. Production amounts to 1300–1800 kWh/m^2 a year, while the annual duration of sunlight totals 2200–3000 h (MEP RK, 2009; Obozov, 2008). Despite these apparently favourable conditions and the political will behind this energy source, the use of solar energy is not widespread in Kazakhstan, due to inbuilt inertia in the national energy system, uncertainty over economic returns and lack of regulatory incentives for private sector investment.

Kazakhstan is the world's largest producer of uranium, at 22,500 t from 17 mines (World Nuclear Association, 2016). Kazakhstan is aiming to construct a nuclear power plant to become operational by the early-2020s, with a 300–1200 MW capacity (WNN, 2014).

Of the total electricity generated, domestic industry consumes 54.2%, households 19.1% (8.4% rural, 7.6% urban, 3.1% suburban), power plants 10.5%, transportation sector 5.4%, agriculture 2.2%, construction sector 1.3% and the remaining 7.3% is lost in distribution (ATFBank Research, 2011; ARKS, 2014b; Soros Foundation, 2015; KEGOC, 2011; MINT, 2011). Households and SMEs are supplied by 179 energy supply organisations with jurisdiction provided by geography, whereas large industrial consumers are supplied directly from the grid (Soros Foundation, 2015; KEGOC, 2016b). Consumption and generation are closely correlated owing to the horizontal and vertical integration of energy-intensive industrial sectors and electricity generation. Thus, approximately 50% of the total electricity generated is supplied directly to the large industrial companies who own the 66 power plants (ATFBank Research, 2011).

3. Methodology

The Kazakh energy sector has followed business-as-usual since Independence, is inefficient, and marked by great potential for change though its natural resources. Yet change under these conditions is challenging, with particularly the evidence base and political appetite for introducing new technologies untested. In light of these challenges, our methodology to support decision-making over electricity generation is developed using structured decision-making based on active local participation coupled with cost-benefit analysis, which is commonly used to make project investment decisions. Both structured decision-making and cost–benefit analyses offer processes that align compellingly with published frameworks for energy-related decision-making. Our CBA uses technical engineering data to drive the commercial premise underlying investment potential, and environmental and social data to drive the wider economic benefits.

Decision analysis methodology has evolved since its origins in the 1960s (Howard, 1966). Today, it is widely used across both academic and corporate arenas (Hammond et al., 1999). For example, Spetzler et al. (2016) suggest that, to maximise the quality of a decision, one requires linked inputs: framing, alternatives, appropriate focused data,

Table 6
Existing and planned electricity generation assets by capacity (billion kWh), 2015–2050.
Source: adapted from KOREM (2016); KEGOC (2016a).

Year	Existing assets							Planned assets (first on-stream date only)					Total existing and planned assets		
	Total	*Gas*	*Oil*	*Coal*	*Hy-dro*	*Wind*	Total	*Gas*	*Coal*	*Hydro*	*Nuc-lear*	*Wind*	*Planned*	*Existing*	Total
2015	**97.67**	8.80	3.88	73.25	8.71	3.03	**3.68**	–	–	1.58	–	2.10	3.68	97.67	**101.35**
2020	**88.29**	7.93	3.50	65.99	7.84	3.03	**44.32**	–	31.57	0.65	7.88	0.53	44.32	88.29	**132.61**
2025	**86.08**	7.70	3.40	64.09	7.62	3.27	**44.32**	–	–	–	–	–	44.32	86.08	**130.39**
2030	**83.86**	7.50	3.30	62.38	7.41	3.27	**46.07**	–	–	–	–	1.75	46.07	83.86	**129.93**
2035	**74.62**	6.64	2.93	55.22	6.56	3.27	**46.07**	–	–	–	–	–	46.07	74.62	**120.69**
2040	**63.62**	5.61	2.47	46.71	5.55	3.27	**46.07**	–	–	–	–	–	46.07	63.62	**109.69**
2045	**38.16**	3.25	1.43	27.00	3.21	3.27	**46.07**	–	–	–	–	–	46.07	38.16	**84.23**
2050	**9.08**	0.54	0.24	4.50	0.54	3.27	**46.07**	–	–	–	–	–	46.07	9.08	**55.15**

clear trade-offs, logic, and commitment to implementation. Our methodology is aligned with Spetzler et al.'s (2016) principles of structured decision-making, and followed three basic steps. In the first, we analysed current consumption and production, and population estimates coupled with official forecasts, to estimate the future electricity balance against the lifespan and generation profile of existing assets and future production assets whose construction was already under way. The second step entailed convening a Framing Workshop with key stakeholders in Kazakhstan, to elicit their perceptions on the challenges facing the domestic electricity sector, to discern Policy Options that the country could consider in delivering energy security, and identify the key sustainability, technical and financial risks they wish integrated to the investment decisions across all Policy Options. In the third step, we modelled the dominant Policy Options from the Framing Workshop for their technological and economic viability in meeting the forecast supply shortfall. The modelling aimed to aid decision-making and, as such, our intention was not to reveal absolutes in monetary terms, but to indicate broad decision pathways for policymakers.

A critical political challenge to making effective decisions is that choosing among policies using traditional cost–benefit analysis is hampered by incomplete information, data and evidence on the options available. When these gaps are primarily handled by having external experts make educated guesses about what the available options are and what parameters should be used to assess them, the resulting estimates frequently lack credence in the eyes of local stakeholders, who may then proceed to ignore the results of the analysis.

Our novel approach sought to minimise some traditional challenges faced with employing Cost-Benefit Analysis for policy development in emerging economies. By using collective expert testimony, we sought to reduce the risk of political rejection of the findings, as identified by Lempert (2014). We used engineering data from similar project builds and operations in Central Asia to ensure our data were realistic and not over-optimistic, as identified by Flyvberg (2005). By using sensitivity analysis based around globally evidenced data points, we sought to reduce risks associated with aggregating attributes of concern by assigning agreed-upon values, as identified by Weyant (2014) and Lempert (2014).

Expert-led framing workshops, stakeholder-led analyses and structured decision-making are increasingly being used to develop policies that can be compared quantitatively (Kass et al., 2011; Creedy et al., 2009). The economic benefits of incorporating the views of multiple disciplines and stakeholders in decisions have been demonstrated extensively (Bessette et al., 2014; Hardisty, 2010). Further, structured decision-making approaches help to deal with multiple challenges, including decision-maker bias (Bond et al., 2008), ambiguity in both stakeholders' risk perceptions and trade-offs (Harclerode et al., 2015), and the integration of environmental and social factors (Hardisty, 2010).

Our methodology brings a mix of challenges and opportunities. Clearly, it is positive that following this approach will ensure that the Policy Options proposed will be ones that are both politically feasible and within the scope of options that policymakers are seriously considering. Yet analogously, we risk that only those Policy Options that are perceived to being contemplated by policymakers will be included. Options were excluded owing to stakeholders' perceptions of technological, financial or political infeasibility. This can lead to a narrower range of Policy Options. For instance, politically in Kazakhstan, price increases sufficiently high to have a discernible impact on energy efficiency are out of the question. Moreover, although future technological improvements in renewable energy technologies are widely anticipated by observers elsewhere, these future improvements cannot be incorporated into the planning process if policymakers do not believe (or at least are not willing to base policy on the assumption that) those improvements will materialise. In summary, this leads to scenarios that are pessimistic in their efficiency and technology assumptions, but on the other hand – significantly – leads to scenarios that policymakers see as realistic options.

Table 7

Forecasts of electricity generation and consumption (billion kWh/ year), 2015–2050. (Sources: KEGOC (2011, 2013); KOREM (2009); author's calculations.)

Factor	2015	2020	2025	2030	2040	2050
Existing electricity generation capacity (billion kWh/year)	101.35	132.61	130.39	129.93	109.69	55.15
Estimated electricity consumption (billion kWh /year)	101.00	124.50	144.05	160.76	186.57	216.52
Shortage/surplus	0.35	8.11	−13.66	−30.83	−76.88	−161.37

In seeking to use CBA to integrate those elements of environmental sustainability and green economy enshrined in national strategies by GoK into energy investment decisions, we risk omitting or understating key ethical standpoints such as intergenerational equity (Toman, 2014) as well as making poor choices about how technological and efficiency gains will change in the future. In particular the lack of information on the distributional issues of energy facing both the off-grid population and those facing energy poverty reduces our ability to represent these risks accurately in our CBA (Woolf et al., 2014).

3.1. Future electricity balance

Continued electricity provision at current prices is a political given, even if it leads to apparently inefficient outcomes; hence, it is assumed that some investment in electricity generation will be subsidised to the extent needed to make it financially viable. The point of this study, therefore, is to identify financially and economically attractive options relative to the current electricity generation mix. Given current trends and prices, the current and predicted supply and demand of electricity have been determined based on data provided by Government ministries and other official sources, including current and planned electricity generation assets (Tables 6 and 7, Fig. 1). Demand forecasts based on anticipated economic growth and population increase from KEGOC and KOREM extend to 2020, while those for Southern Grid extend to 2035. We extrapolated to the year 2050 by assuming the Southern Grid demand forecasts to 2035 held for the entire country. This is a reasonable assumption, given the Southern Grid economy's representativeness of the national economy. Our forecasts used are 4% annual demand growth to 2020, 3% from 2021 to 2025, 2.4% from 2026 to 2030, and 1.5% from 2031 to 2035. In the absence of better data, a 1.5% annual demand growth rate has been extrapolated from 2036 to 2050 for the entire country (KEGOC, 2011, 2013; KOREM, 2009).

Fig. 1 illustrates Kazakhstan's electricity generation shortfall. Around 2020, the existing electricity generation assets begin to approach the end of their intended lifespan and, as they are decommissioned, the total electricity generated begins to decline. By 2022, at current prices, demand is greater than supply and this generation shortfall grows continuously to 2050.

In principle, permitting the electricity price to rise would encourage consumers to reduce demand. Therefore, with an own price demand elasticity of about −0.3,[1] continuous price increases of some 5% a year from 2020 onward would be enough to close the supply shortfall – even if no new capacity is brought online. Obviously, even a few years of annual 5% price increases would be enough to make investments in new capacity more attractive. However, as noted earlier, because

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[1] There appear to be no published academic estimates of own price demand elasticities for electricity for the region, but most studies in other parts of Asia (as well as in other parts of the world) have found price elasticities ranging from −0.1 to −0.5, making −0.3 a reasonable approximation.

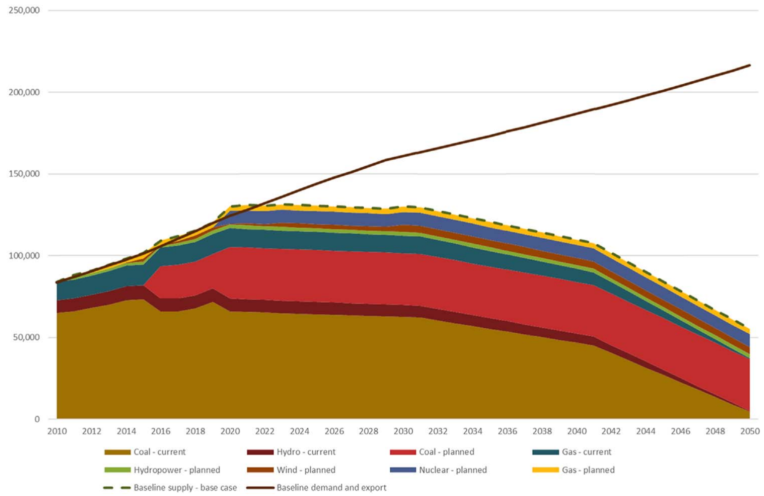

Fig. 1. Electricity supply shortfall – Existing and projected baseline power supply trajectory by generation type, 2010–2050 (millions kWh).

electricity pricing is politically sensitive, it is highly unlikely that the Kazakh Government would permit price increases of 5% a year, or that it would stay in power for long if it did so. Realistically, therefore, the supply shortfall would need to be closed at unchanged real electricity prices, making planning for new investment necessary years before the supply shortfall materialises.

3.2. Framing workshop

3.2.1. Approach

In order to access the collective expert knowledge of local stakeholders and experts, we convened a Framing Workshop with them on 17 June 2011, following an analysis of potential participants identified by their peers and a screening of the membership of key associations, as well as through academic research. Participants included representatives from key government ministries, the private sector, international and local non-governmental organisations, and international financial institutions. The focus was to develop a list of Policy Options that local stakeholders regarded as realistic potential alternatives to meet the future generation shortfall.

3.2.2. Policy option development

A facilitated session was held during the Framing Workshop to elicit from the participants a long-list of Policy Options. The session produced a range of innovative Policy Options, including some unseen in Kazakhstan. In total 30 were identified. Subsequently this list was reduced to seven owing to some duplication, technical and financial infeasibility, and lack of alignment with stated government policy.

None of the Policy Options completely removes the need for additional "traditional" generation assets to be constructed to fill the forecast generation shortfall. Therefore non-BAU Policy Options are modelled on the business-as-usual (BAU) scenario. The five scenarios and the seven Policy Options they encompass are as follows:

The BAU scenario – Policy Option 1: Investments are made to ensure a continuation of the current mix of electricity generation with no change in energy policy to 2050 – 81.6% coal, 10.2% hydropower, 8% gas, < 1% renewable (see Table 2).

The natural gas scenario – Policy Options 2 and 3: Expanding natural gas utilisation using considerable domestic reserves. Costings include infrastructure upgrades to accommodate expanded natural gas utilisation. Assets will use Combined Cycle Gas Technology, with two Policy Options for the scale of investment. Policy Option 2 entails achieving the lower 15% target by 2050, and Policy Option 3, the higher 30% target by 2050. In both cases, the substitution of coal delivers positive sustainability impacts.

The renewable energy scenario – Policy Options 4 and 5: For the purposes of this analysis, we make a distinction between hydropower and non-hydropower renewable energy (herein "renewable energy"). This scenario entails establishing and expanding new renewable electricity sources excluding hydropower. Owing to the outcomes from the Framing Workshop, which indicated that the political, technical and financial viability for scalable technology lay with wind (Table 8), priority was given to wind rather than solar technology with a maximum generation limit of 20% of baseline demand assumed. The capacity factor used is 30% in line with findings by ESMAP (1997) for Kazakhstan and REN21 (2017) for Eurasia. The potential of the full range of renewable energy sources was discussed at the Framing Workshop – including concentrated solar, PV solar and biomass. In discussion with stakeholders, the renewable energy option with two targets was agreed to reflect the most likely pathway for Kazakhstan. Policy Option 4, the lower target, would achieve 15% of electricity generation by 2030 in this scenario, while Policy Option 5, the higher target, would achieve 30% of electricity generation by 2050.

The hydropower scenario – Policy Option 6: This entails prioritising both small- and large-scale hydropower investments to a level of 20% of all electricity generation by 2050. The stakeholders at the Framing Workshop support this Policy Option owing to previous hydropower installations, widespread perceived social benefits from the dispersed nature of electricity generation potential (particularly from small-scale hydropower plants which are typically in more rural areas), the relative availability of technology, and the climate and other environmental benefits. However, the integration of the full range of social benefits to our analysis was not deemed critical by the experts. Indeed, there was insufficient data on the extent and distribution of energy poverty in Kazakhstan to develop meaningful estimates for modelling purposes.

The nuclear scenario – Policy Option 7: This entails building the first nuclear facility in Kazakhstan to utilise domestic uranium deposits. This scenario includes the cost of garnering international support for building the capacity to implement a new regulatory regime around

Table 8
Assumptions and variable estimates for this study, elicited from the Framing Workshop and cross-referenced with other sources.

Factor	Description	Framing Workshop outcome	Other sources
Growth rates in electricity demand	Extrapolated from predicted annual demand growth rates in the Southern Grid to 2035: 3.0% (2021–2025), 2.4% (2026–2030), and 1.5% (2031–2050)	Use official data	KEGOC (2011); KOREM (2009); MEP RK (2009)
Power plant	Capacity, build time, capacity factors, capital expenditure	Use international benchmarks and locally appropriate data where missing from the former Soviet Union (FSU)	Using benchmarked data for other power plants across FSU countries, coupled with expert estimations by WorleyParsons engineers from facility experience in Uzbekistan (WorleyParsons and Acclimatise, 2013) Industry benchmarks consulted include IEA (2011); Merrow (2014); and WEC (2009)
Renewable energy targets	Policy Options 3.1 and 3.2 – Low: 15% through 2050; High: 30% through 2050	Develop policy options on low and high targets, with a focus on wind power	IRENA (2015)
Hydropower	Policy Option 4 – Hydropower to 20% of generation through 2050	Develop policy option on hydropower to reflect the need for reliable rural supply of electricity	ATFBank Research (2011)
Electricity tariffs (c/kWh)	International used 15c/kWh: owing to reported global range (10c–20.5c/kWh)	Use prevailing prices	World Bank (2010)
Discount rate – Financial	8%	Use local rate of 7.5–10% in line with National Bank of Kazakhstan	ADB (2015); EW (2015); NBK (2016)
Discount rate – Economic	3.5%	Use local rate of 3–4% as used to guide policy development	ADB (2015); HM Treasury (2003)
Water	US\$1/m^3 (high: US\$0/m^3; low: US\$3.5/m^3)	Use HM Treasury data from the United Kingdom	HM Treasury (2003)
Sulphur dioxide emission shadow price	US\$630/t	Use global data	Burtraw and Szambelan (2009); Chan et al. (2012)
Carbon dioxide emission shadow price	US\$22/t	Use European Trading Scheme data	EU (2012)
Sensitivity – Shadow prices	Carbon dioxide, sulphur dioxide, nitrogen and water – varied between low–base–high	Build in sensitivity to shadow prices and use global benchmarks	(See Table 10)
Sensitivity – Resource prices	Coal, gas, nuclear – varied between low–base–high	Build in sensitivity to resource prices, using trends in global prices over the past 20 years	(See Table 12)

nuclear power, where it could meet a target of 20% of all electricity generated by 2030. The costs and benefits of locally available uranium deposits are reflected, in particular investments in refining. The additional cooling water requirements of nuclear power are accounted for, with costs of material waste disposal incorporated into the operating costs. This is among the costliest solutions, with a considerable capital expenditure requirement (US\$5 billion). We expect the greenhouse gas emissions associated with this Policy Option to be lower than for current electricity generation, providing benefit through the shadow pricing of environmental factors discussed below.

3.2.3. *Externalities*

In order to ensure our methodology integrated the reality of delivering complex projects in Kazakhstan we elicited a list of monetary rate assumptions and technical data prices (Table 8). Further to integrate the reality of sustainable development for Kazakhstan into the decision-making support process, we elicited a list of externalities to quantify for each Policy Option, ensuring that the local definition would prevail. For instance, water and carbon dioxide emissions were seen as critical, whereas biodiversity was not (Table 8).

We cross-referenced the participants' assumptions and variable estimates with the literature, as indicated in Table 8. The value of using data, assumptions and estimates that resonate with stakeholders is evidenced in enhanced perception of outcomes, broader participation, and a greater willingness to engage in the process of change (Hardisty, 2010).

Considering the dominance of energy generation in the national level of greenhouse gas emissions, at 85% (UNFCCC, 2014) coupled with political developments around an ETS, it is no surprise that participants ranked carbon dioxide emissions highly when constructing a list of the environmental factors they considered critical for basing decisions among Policy Options. Other greenhouse gas emissions were considered at the Framing Workshop – including methane, perfluorocarbons, hydrofluorocarbons, sulphur dioxide and nitrous oxide. Methane accounts for an estimated 17% of Kazakhstan's GHG emissions but was not considered critical by stakeholders owing to the political drive behind carbon dioxide emissions reduction, and further perfluorocarbons and hydrofluorocarbons account for less than 1% of greenhouse gas emissions in Kazakhstan and data were considered insignificant (UNFCCC, 2014).

By taking our methodological lead from the experts in Kazakhstan, clearly this approach limits the analysis of costs and benefits somewhat. Specifically, the wider social and economic benefits of renewable energy option and hydropower in serving rural areas and reducing energy poverty. It is clear that energy investments may stimulate retail markets, manufacturing and innovation, but these are typically difficult to measure accurately (Woolf et al., 2014) and therefore only direct benefits are used. Further, the full indirect and induced benefits of developing new energy technology supply chains in Kazakhstan are not reflected in this analysis owing to difficulty in developing these data and the perceived lack of acceptance of these data by the experts.

3.3. *Modelling*

3.3.1. *Policy option modelling at base case*

A cost–benefit analysis of the seven identified Policy Options was developed to meet the anticipated generation shortfall (Table 7) using electricity generation profiles incorporating technical, financial and environmental data (Table 9) and base case shadow prices for the environmental factors (Table 10). Also included are enhanced international sales of coal from the substitution of fuel sources for electricity generation.

Our analysis compares among Policy Options using financial and

Table 9
Summary of technological, environmental and financial profile of new electricity generation assets.
Source: WorleyParsons and Acclimatise (2013).

Generation type	Typical installed capacity	Build time	Capital expenditure	Operating expenditure – Non-energy	Generation	Carbon dioxide emissions	Water use	Power during project lifespan	Capital expenditure
	MW	*Months*	*Million US $/billion kWh*	*US$/MWh*	*Billion kWh/ year*	*t CO_2-e/ MWh*	*'000 t/h*	*'000 billion kWh*	*Million US$*
Gas	400	36	4.24	3.8	2.93	0.39	20	113	480
Coal	400	48	8.34	4.8	2.97	0.90	50	110	920
Nuclear	1000	60	17.62	6.0	7.88	0	200	284	5000
Small-scale hydropower	10	18	12.68	5.1	0.04	0	0	2	20
Large-scale hydropower	150	60	25.37	2.2	0.66	0	0	24	600
Wind	50	24	23.41	10.9	0.11	0	0	4	100
Solar	20	18	30.05	12	0.32	0	0	13	384

Table 10
Shadow price sensitivity ranges for environmental factors (US$), 2013.

Environmental factor	Units	Sensitivity			Sources
		Low	Base	High	
CO_2	US$/t CO_{2-e}	0	22	85	EEA (2016); EU (2012); Hardisty (2010); IPCC (2015); Stern (2006)
SO_x	US$/t	0	630	1160	Burtraw and Szambelan (2009); Chan et al. (2012); Hardisty (2010)
NO_x	US$/t	0	770	3377	Hardisty (2010); IPCC (2015)
Water	US$/$m^3$	0	1.00	3.50	Hardisty (2010); HM Treasury (2003)

economic net present values to proxy for the desired returns on investments of decision-makers in both commercial and government. Framing Workshop participants provided the discount rates that are used within Kazakhstan to make investment decisions at 3.5% and 8% respectively for economic and financial discount rates. The financial discount rate is in line with the Central Bank of Kazakhstan base discount rates of 7.5–10% during 2001–2015 (EW, 2015; NBK, 2016), and the economic discount rate is in line with those used in the literature (ADB, 2015; HM Treasury, 2003; Woolf et al., 2014). Although the difference is unusually large and potentially drives large part of the gap between financial and economic outcomes of our analysis, one distinct advantage of these discount rates is their acceptance by stakeholders within Kazakhstan.

Table 11 illustrates the different electricity generation, capital costs and externalities incurred by the Policy Options relative to Policy Option 1 (BAU). Total electricity generation among the six alternative options aims to fulfil the domestic needs and contracted export requirements, and as such is marginally more efficient than BAU at supply equalling demand. All options use less coal, which is understandable given the significance of divesture from coal, both politically and environmentally.

3.3.2. Sensitivity analysis

Framing Workshop participants were keen for risk to be built into both the cost of resource inputs (Table 12) and a range of shadow prices for environmental factors (Table 10). The shadow price ranges in Table 10 are built on international benchmarks and incorporate benefits transfer from FSU case studies, where possible. Base sulphur dioxide (SO_2) emissions values are from the US Emissions Trading Scheme (ETS), with values used in the sensitivity analysis ranging from the current financial cost of emissions in Kazakhstan (zero) to the highest price paid on the secondary spot market of the ETS in 2010. Carbon dioxide emissions values used in the sensitivity analysis range from the current financial cost of emissions in Kazakhstan (zero) to the social cost of carbon reported in the Stern Review. The base case is the average carbon dioxide (CO_2) price on the EU ETS in 2010. Water values range from the current financial cost of water in Kazakhstan to users (zero) to the highest willingness-to-pay figure from international watersheds.

Volatility in resource prices transpires as a risk for resource-rich nations like Kazakhstan. Using a range of values to ascertain through our CBA how robust differences are between our Policy Options, will enable decision-makers to comprehend the risks to the analysis and their decisions. The ranges are based on historical and published data as well as private data used to inform commercial investment decisions.

4. Results

Net present values (NPVs) were calculated to 2050 to enable comparison and decision ranking among Policy Options. In line with typical project appraisal analysis using CBA, we derive the financial Net Present Value (FNPV) and the Economic Net Present Value (ENPV) of each Policy Option to 2050. In order to provide practical support for decision-making over electricity investments in Kazakhstan, we compare each Policy Option with the BAU Option 1.

4.1. Policy options at base case

The investment in electricity generation to ensure energy security to 2050 in Kazakhstan is estimated at $67 billion for BAU. The Policy Options cost between US$ 56.8–107.8 billion, with two cheaper than BAU, saving up to 15% and four more expensive by 15–59% (Table 13). To fill the looming electricity supply shortfall, Options 2 and 3 will be cheaper than Policy Option 1 (BAU) and Option 5 will cost less in operation. The simple interpretation is that gas is relatively cheaper per unit of energy to operate and build than coal whereas renewable energy, hydropower and nuclear are more expensive to build although hydropower is cheaper to operate.[2]

The *financial* analysis indicates that investments in gas should be

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[2] The reinvestments and new investments needed to maintain the electricity generation mix associated with each Policy Option (1–7) are described in Appendix A.

Table 11
Electricity generation, costs and externalities, by Policy Option, for selected years to 2050, values relative to Policy Option 1 (BAU).

		Energy		**Generation**						**Capital costs**		**Externalities**			
Policy	**Year**	Supply gap (GWh)	Potential supply (GWh)	Coal (GWh)	Gas (GWh)	Large-scale hydro power (GWh)	Wind (GWh)	Small-scale hydro power (GWh)	Nuclear (GWh)	Capital expenditure Annual (US$ m)	Operating expenditure Annual (US$)	Carbon emissions (t CO2-e)	NOx emissions (t)	SOx emissions (t)	Water use (kℓ)
Policy Option 1 (BAU)	**2020**	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2030	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2040	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2050	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Policy Option 2 (Gas 15%)	**2020**	0	−2649	−2978	2931	0	0	0	0	−162,000,000	−2,978,400	−1,518,984	−688	−1072	−3,797,460
	2030	0	320	−5957	5862	−1337	0	0	0	178,000,000	−8,847,600	−3,037,968	−1376	−2145	−7,594,920
	2040	0	−1889	−5956	5861	0	−1533	0	0	437,000,000	−22,666,500	−3,037,968	−1376	−2144	−7,594,920
	2050	0	65	−8935	8792	−668	876	0	0	0	−832,200	−4,556,952	−2064	−3217	−11,392,380
Policy Option 3 (Gas 30%)	**2020**	0	−2649	−2978	2931	0	0	0	0	−300,000,000	−2,978,400	−1,518,984	−688	−1072	−3,797,460
	2030	0	320	−26,806	29,308	−2005	0	0	0	−214,000,000	−19,823,880	−12,509,280	−6076	−9650	−31,645,500
	2040	0	−1889	−29,784	35,169	−3341	−1533	0	0	−186,000,000	−31,084,860	−12,866,688	−6648	−10,722	−32,911,320
	2050	0	2131	−35,741	43,961	−4009	−2081	0	0	0	−33,136,890	−14,743,080	−7908	−12,867	−37,974,600
Policy Option 4 (RE 15%)	**2020**	0	−2649	−2978	0	0	329	0	0	340,000,000	−10,715,670	−2,680,560	−804	−1072	−6,329,100
	2030	0	320	−14,892	−2930	−2005	20,148	0	0	−72,000,000	132,477,480	−14,564,376	−4136	−5361	−34,177,140
	2040	0	−1585	−17,870	−2931	−3341	22,557	0	0	192,000,000	141,548,460	−17,244,936	−4940	−6433	−40,506,240
	2050	0	−63	−17,870	−2931	−4009	24,747	0	0	0	163,974,060	−17,244,936	−4940	−6434	−40,506,240
Policy Option 5 (RE 30%)	**2020**	0	−2649	−2978	0	0	329	0	0	340,000,000	−10,715,670	−2,680,560	−804	−1072	−6,329,100
	2030	0	320	−14,892	−2930	−2005	20,148	0	0	754,000,000	132,477,480	−14,564,376	−4136	−5361	−34,177,140
	2040	0	−1889	−26,805	−5862	−6014	36,792	0	0	1,205,000,000	236,721,480	−26,448,192	−7468	−9650	−62,025,180
30	**2050**	0	608	−44,676	−5861	−7350	51,136	0	0	0	370,633,410	−42,531,552	−12,292	−16,083	−74,981,220
Policy Option 6 (Hydropower)	**2020**	0	−2649	−2978	0	0	0	315	0	413,000,000	−12,687,984	−2,680,560	−804	−1072	−6,329,100
	2030	0	320	−17,871	−2930	13,106	0	7529	0	123,000,000	−29,788,818	−17,244,936	−4940	−6433	−40,506,240
	2040	0	−1889	−20,848	−2931	15,667	−657	7529	0	112,000,000	−45,464,838	−19,925,496	−5744	−7505	−46,835,340
	2050	0	−585	−20,849	−2931	16,870	−1205	7529	0	0	−48,541,788	−19,925,496	−5744	−7506	−46,835,340
Policy Option 7 (Nuclear)	**2020**	0	−2649	0	0	0	0	0	0	525,000,000	0	0	0	0	0
	2030	0	320	−5957	0	−2005	0	0	7884	642,000,000	14,375,160	−5,361,120	−1608	−2145	14,147,400
	2040	0	−1889	−11,913	−2931	−3341	−1533	0	23,652	35,000,000	49,472,100	−11,883,816	−3332	−4289	52,568,760
	2050	0	8457	−23,827	−2931	−2672	−1533	0	39,420	0	88,340,220	−22,606,056	−6548	−8578	80,863,560

Table 12
Sensitivity ranges for resource costs (US$), 2013.

Category	Units	Sensitivity			Key sources
		Low	Base	High	
Coal	US$/GJ	0.66	0.73	2.42	ADB (2012); ANMR (2010); ECS (2010); USCS (2013); WorleyParsons and Acclimatise (2013)
Gas	US$/GJ	1.07	1.26	4.94	ANMR (2010); ICLG (2016); NRC (2015); WorleyParsons and Acclimatise (2013); Yenikeyeff (2008)
Nuclear	US$/MWh	9.41	9.9	10.89	Black and Veatch (2012); World Nuclear Association (2016); WorleyParsons and Acclimatise (2013)

considered more favourably, with both gas Policy Options returning a financial net present value (FNPV) in excess of BAU (Table 14). The Policy Options for hydropower, nuclear and renewable energy all return an FNPV below BAU, and are not commercially viable alternatives to BAU at current prices. These results show the relative expense of new technology development for a resource-rich country like Kazakhstan, even when compared with a relatively inefficient power system.

Fig. 2 demonstrates the broad categories of marginal economic cost and benefit for the Policy Options over BAU. Capex, Opex, carbon dioxide emissions and international sales are key components driving the NPV for these Policy Options.

Furthermore, Figs. 3 and 4 illustrate the differences in the sequencing of costs for capital and operations respectively across the seven Policy Options, and the financial investments necessary to ensure electricity generation self-sufficiency. Nuclear and both renewable energy policy options are costly to build and operate.

The *economic* analysis indicates both gas and hydropower Policy Options returning an economic net present value (ENPV) in excess of BAU (Table 14, Fig. 2). The Policy Options for nuclear and renewable energy all return an ENPV below BAU, and thus do not bring sustainable value to Kazakhstan.

A significant change is noticed across Policy Options relative to BAU, with all alternative Policy Options producing lower emissions than BAU and all except Policy Option 7 (Nuclear) leading to lower water usage than BAU, see Table 15.

4.2. Policy options under sensitivity

Our sensitivity analysis considers decisions under fluctuating costs and allows analysis of the changes in ranking among Policy Options for indications of the scale of the risks for decision-makers.

Under sensitivity to fluctuating resource costs (Tables 16 and 17), the rankings for Policy Options remain largely unaffected, indicating that, within expected and historical parameters, changes in prices do not affect our policy decisions. Indeed, across resource costs, we find only at the highest sensitivities to input prices, do Policy Options rankings change – i.e. when coal costs over US$1.72/GJ and gas over US$3.30/GJ, which are both considerably higher prices than expected for these resources. Notably, both markets are depressed: coal prices have fallen since 2009, while gas prices in Kazakhstan and the FSU have remained stagnant since 2011.

The sensitivity analysis of the seven Policy Options to *fluctuating values of non-technical environmental variables* highlights some sensitivity of the ENPV to carbon dioxide emissions costs, but no Policy Option ranking changes for the other variables analysed here (Tables 17 and 18).

The scale of the challenge to promote renewable energy and deliver on the Government of Kazakhstan's Visions of a Green Economy and a Sustainable Future is illustrated by Table 18. The Table shows that only at a shadow price for carbon dioxide approaching the social cost estimated by Stern (2006) do our rankings of the seven Policy Options change. Also, only at that point does BAU become a least-favourable option, while renewable energy scenarios other than hydropower become economically attractive. Indeed, at a shadow price exceeding US$50/t, the renewable energy scenario Policy Options outstrip the BAU scenario, but still perform worse than the gas scenarios.

5. Conclusions and policy options

We have sought to support decision-makers wishing to develop a sustainable energy economy in fossil-fuel-based carbon-intensive Kazakhstan, at a time when multi-billion dollar investments are being considered to ensure energy security to 2050. Our methodology focused on identifying robust outcomes that could inform policy-makers' decisions when it came to electricity generation policy and investments in the context of key challenges, namely weak data, uncertain stakeholder views, and the Kazakh Government's unassimilated goals of energy security and sustainable development. By taking a structured approach to decision-making coupled with Cost-Benefit Analysis which draws on local expertise to produce outcomes that both expand current thinking and merit serious consideration.

Our findings are that the government should turn from BAU, create incentives to enable less coal and more gas and hydropower for electricity generation. In particular, gas is cheaper and commercially viable, indicating strong existing incentives for innovative institutional and financial mechanisms to develop this sector – particularly PPPs, and even privatisation.

The *BAU* scenario is currently based on using abundant coal resources, but this is not the primary policy: we find gas and hydropower to have greater feasibility. Aligned with the Kazakh Government's Green Growth goals, our findings further demonstrate the dwindling significance of coal politically, financially and economically. Indeed, at higher shadow prices close to the social cost of carbon, the BAU scenario is the worst performer.

Gas is a dominant policy, both financially and economically, but it

Table 13
Costs of Policy Options, relative to BAU, 2010–2050 (US$ million, 2010).

Policy Option	Capital Expenditure *Total (US$ million)*	Operating Expenditure *Total (US$ million)*	Capital Expenditure *Annualised (US$ million)*	Operating Expenditure *Annualised (US$ million)*
BAU	0	0	0	0
GAs15	− 1120	− 285	− 28	− 7
GAs30	− 9340	− 789	− 234	− 20
RE15	13,300	3724	333	93
RE30	34,040	5729	851	143
Hydropower	11,400	− 1103	285	− 28
Nuclear	13,360	850	334	21

Table 14
Capital costs and Net Present Value (economic and financial) of policy options at base case (marginal to business-as-usual), to 2050 (billion US$).

Policy Option No.	Policy option description	Capital cost (capital expenditure and operating cost)	Capital cost marginal to BAU	Net present value compared to base case	
				Financial NPV	*Economic NPV*
1	Business-as-usual	66.95	0	0	0
2	Gas 15%	65.55	−2%	464	1738
3	Gas 30%	56.83	−15%	1109	7842
4	Renewable energy 15%	83.98	25%	−1556	−3317
5	Renewable energy 30%	106.72	59%	−1912	−8336
6	Hydropower 20%	77.25	15%	−1340	423
7	Nuclear 20%	81.16	21%	−689	−5414

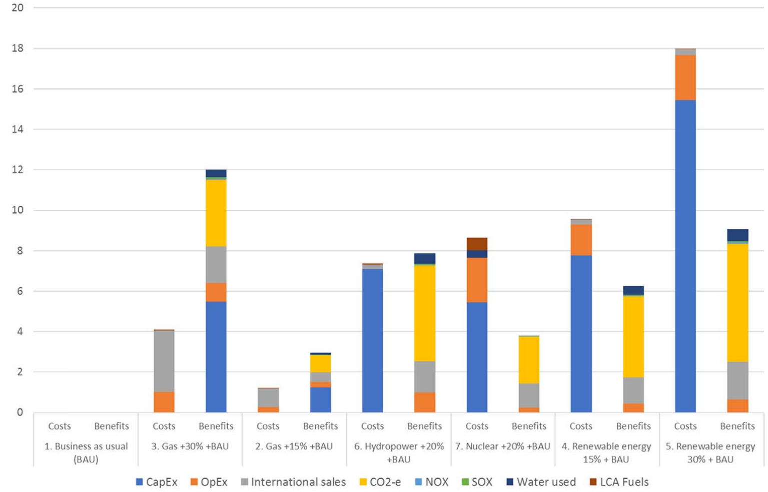

Fig. 2. Economic net present value of policy options by component cost and benefit factors, relative to BAU, at base case, 2010–2050 (US$ billion).

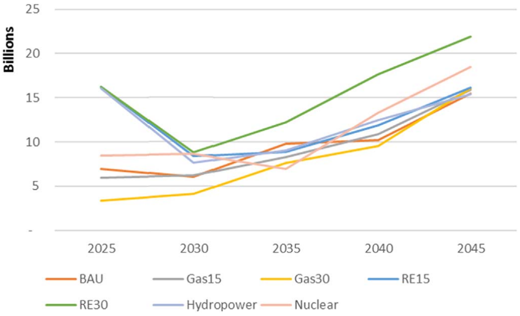

Fig. 3. Cumulative capital cost for each Policy Option ensuring electricity self-sufficiency, 5-year intervals, 2020–2050 (US$ billion).

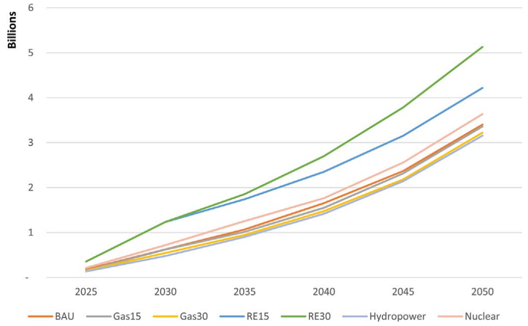

Fig. 4. Operating cost for each Policy Option ensuring electricity self-sufficiency, 5-year intervals, 2020–2050 (US$ billion).

is currently underserved. We suggest considering a Gas Masterplan for Kazakhstan to support delivery of the goals of sustainable economic growth and energy security, particularly in light of necessary environmental safeguards that would be needed to ensure that natural gas leaks from gas wells and pipelines do not diminish the environmental benefits from replacing coal in the electricity generation mix. The existence of long-term natural gas contracts between Russia and its neighbours Turkmenistan and Uzbekistan, hints further at commercial potential. Indeed, the role of natural gas is promoted increasingly in the FSU and, in Kazakhstan, natural gas is being recognised through investments by the European Bank for Reconstruction and Development (announced in October 2016) with €245 million is going towards upgrading underground storage and maintaining pipelines to reduce losses, increase energy efficiency and support energy security (EBRD, 2016).

The *hydropower* scenario is an economic option under base case conditions, and its economic feasibility increases under future scenarios where the environment is valued more highly. Nonetheless, there are concerns raised by hydropower's lack of financial viability. In order to avoid the Government being saddled with the full costs of invest-

Table 15
Externalities of Policy Options, relative to BAU, 2010–2050.

Policy Option	Carbon Emissions *(ton CO2-e)*	NOx Emissions *(ton)*	Sox Emissions *(ton)*	Water use *(kL)*
BAU	0	0	0	0
GAs15	– 68,890,392	–35,304	–56,827	– 175,948,980
GAs30	– 328,726,008	– 165,296	– 264,833	– 836,707,020
RE15	– 378,227,016	– 108,564	– 141,530	– 888,605,640
RE30	– 622,336,680	– 178,528	– 232,667	– 1,400,071,380
Hydropower	– 449,529,912	– 128,556	– 167,263	– 1,055,693,880
Nuclear	– 283,960,656	–81,452	– 106,148	968,054,460

ment, there is a need for new policies to make this form of energy more attractive and allow it to garner commercial interest. One way to achieve such policy aims would be to institute an incentive-based tariff that would force grid operators to buy electricity from small-scale hydropower plants at a fixed rate in excess of the tariffs applicable to thermal power plants. Such policy approaches have proved successful in providing incentives for expanding renewable investment in India, the Philippines and South Africa (KPMG, 2015). In Kazakhstan, such a policy, coupled with, for example, government-backed soft loans and a lowering of current initial and operating capital requirements, could assist in bridging the missing finance, and enhance economic viability, although it could conceivably delay development of innovative financing structures such as PPPs. Regardless of the exact setup chosen, the results presented here suggest that supportive policies that encourage hydropower development could be socially beneficial.

Renewable energy is often considered a clear win for energy security and global environmental and social values, but our findings provide little support for this in Kazakhstan's case. Both financially and economically, we find limited evidence on which to base a recommendation to pursue renewable energy. This finding gives some concern that we have not sufficiently integrated all the positive spillovers from renewable energy including cleaner electricity production and the inclusive benefits from distributed energy resources. Clearly this is an option that requires further analysis once new data and insights are available; notably, the anticipated future cost reductions for these technologies, which are not included here as they were not seen as realistic by local stakeholders, could change the picture substantially if they materialise. However, we find that the Government of Kazakhstan could achieve its goals of a Green Economy and energy security, by switching from coal to natural gas and hydropower as renewable energy sources.

The *nuclear* scenario is attractive in respect of ample domestic uranium deposits, but it is expensive considering the cost of new technology development, necessary capacity-building, development of associated input and ancillary industries, and the development of a social licence to operate make it unviable alternative to BAU or against the alternative Policy Options.

Furthermore, the Kazakh Government wishes to maintain the affordability of electricity, deliver it continuously and increase the reliability of supply for both residents and industry, with an emphasis on the currently unserved. This typically means maintaining artificially low prices, which may further undermine investment incentives, delay development of enabling structures such as PPPs, and even destabilise the energy system. A desired synergy of decentralised provision and reliability is conceivably possible with appropriate deployment of renewable technologies in mountainous areas that are currently off-grid. Yet such solutions to rural energy poverty are not currently part of the political discourse.

In practice, the scale of the necessary financial investments required in electricity generation, coupled with its criticality for the nation, typically means consortiums of developers with complementary skill sets are required to establish and develop the energy investments. Our findings suggest that the Vision for Kazakhstan is best served by opening discussions over future investments with potential consortium members in the natural gas and hydropower industries. Furthermore, these two industries have separate groups of stakeholders and investors, which should avoid the cross-subsidisation of one form of electricity generation by another, and with the right investment regimes developed, hydropower and gas could be potent complements to one another. Hydropower and gas are complementary generation options in several ways, specifically financially with natural gas having relatively low capital costs and variable fuel costs, while hydropower

Table 16
Sensitivity of policy option rankings to prices (US$, 2013) of resource inputs, 2010–2050.

Resource input	Sensi-tivity	Value (US$)	Description of changes to policy option rankings
Coal US$/GJ	Low	0.66	No change in rankings among policy options. Lower price increases the viability of BAU scenario only slightly.
	Base	0.73	Global coal prices have been falling since 2012. Production in Kazakhstan has increased and is expected to increase further, coupled with expectations that demand will persist, increasing 0.4% annually to 2040. These conditions indicate that our base value remains a good indicator (Rowland, 2016; Bauerova and Carr, 2016). Coal is likely to remain the most affordable fuel for power generation in many developing and industrialised countries for decades (Speight, 2012) and recent events do not alter this likelihood.
	High	2.42	Viability of the BAU scenario diminished with higher prices for its main input coal (79%) even when local production potential is taken into account. Hydropower becomes the third most viable option behind Policy Options 3 & 2 overtaking Policy Option 2 at US$1.72/GJ, while Policy Option 5 (Renewable Energy +15%) exceeds Policy Option 1 at US$2.42/GJ.
Gas US$/GJ	Low	1.07	No change to policy option rankings.
	Base	1.26	Since 2012, prices for gas have not increased in Kazakhstan although supply has risen, indicating that the base case remains a strong indicator of current and future pricing. Prices charged to Kazakhstan's neighbours through gas distribution networks have risen (Kosolapova, 2016; Levit, 2016).
	High	4.94	The gas-heavy Policy Options 2 and 3 lose their economic edge, and are ranked lower than the hydropower and BAU scenarios. At US$3.30 Policy Option 2 is lower than Policy Option 1, and at US$3.73 Policy Option 3 is lower than Policy Option 1.
Nuclear US$/MWh	Low	9.41	No change to policy option rankings. Small increase in the viability of Policy Option 7.
	Base	9.90	Since 2012, the supply of uranium to the market has grown considerably, mostly owing to Kazakhstan exceeding its self-imposed production limit by 10% in 2013 (World Nuclear Association, 2016). This indicates the base case is a reasonable approximation of prices.
	High	10.89	No change to policy option rankings. Small reduction in the viability of Policy Option 7.

Table 17
Sensitivity of policy option rankings to shadow prices of emissions (US$, 2013), 2010–2050.

Emission category	Sensi-tivity	Value (US$)	Description of policy changes
Carbon dioxide (US$/t CO_2e)	Low	0	Change to policy option rankings (see Table 13)
	Base	30	Carbon dioxide taxation and shadow pricing have grown in acceptance globally. Kazakhstan has investigated legislating for the establishment of a financial incentive system to reduce domestic emissions. The global price of carbon dioxide emissions has fallen rather than risen over the period 2012–2016, with the European Union's Emissions Trading Scheme spot price being €3.91/ US$4.29, but the carbon taxes – both planned and operational – are seeking US$30 as a reference base case. The social cost of carbon has been re-estimated at US$220, but this is a long-term goal.
	High	85	Change to policy option rankings (see Table 13)
Sulphur dioxide US$/t	Low	0	No change in rankings
	Base	630	The establishment and enforcement of SO_x emissions targets remain a distant objective, but the relevance of the base case remains.
	High	1160	No change to policy option rankings
Nitrogen oxide, US$/t	Low	0	No change to policy option rankings
	Base	770	The establishment and enforcement of NO_x emissions targets remain a distant objective, but the relevance of the base case remains.
	High	3377	No change to policy option rankings
Water US$/$m^3$	Low	0	A zero value on water has an impact on the viability of Policy Option 6 alone, pushing it to lower than Policy Option 1 (at less than US$0.11/$m^3$). At almost any rate placed on water in the decision-making process, hydropower is preferable to Policy Option 1. This is borne out with hydropower being a variable that has some – albeit not unfettered – support from policymakers. When other factors that SMHPPs enable are taken into account, such as serving the unserved with power in rural areas and the water jobs multiplier, the case for hydropower as a mainstay for Kazakhstan is secured.
	Base	1.0	Global use of economic water values remains at the core of the promotion of environmental stewardship. It also continues to be a core part of decision-making in some countries, notably the UK, where the value of US$1/$m^3$ is still the reference base-case for calculating policy relevance.
	High	3.5	No policy option ranking changes for higher values of water. Indeed, Policy Option 6 only becomes more viable than Policy Option 2 at values greater than US$4.19/$m^3$, which are considerably higher than values used for policy advice or estimated elsewhere.

Table 18
Sensitivity to differences in the shadow price of carbon dioxide, ranked by economic net present value (billion US$), to 2050.

Policy options		US$0/t		US$22/t		US$85/t	
No.	*Scenario*	*Net present value (bn US$)*	*Ranking*	*Net present value (bn US$)*	*Ranking*	*Net present value (bn US$)*	*Ranking*
1	Business as usual	0	3	0	4	0	7
2	Gas 15%	904	2	1738	2	4131	5
3	Gas 30%	4595	1	7842	1	17,161	1
4	Renewable energy 15%	−7312	5	−3317	5	8140	3
5	Renewable energy 30%	−14,740	7	−8336	7	7703	4
6	Hydropower	−428	4	423	3	13,921	2
7	Nuclear	−7781	6	−5414	6	1189	6

has higher capital costs but virtually nil fuel costs (Lee et al., 2012).

In the analysis presented here, several assumptions have been made that should be re-examined as better data and improved technological solutions become available. The key assumptions are our estimated costs of generation assets in US$ per GWh, which we find is an appropriate measure. However, improvements could be made to decision-making and economic efficiency if we ensure that all prices are reflected as shadow prices. Moreover, to adequately distinguish between Policy Options, our shadow price values should ideally be extended in order to account for the true economic value of power, including its positive and negative externalities. Our research and insights would benefit from a greater level of detail not only on the Policy Options considered, their full environmental costs and benefits, and also on the sequencing of the costs of their implementation. The growing body of evidence on risks and uncertainty associated with environmental and social factors will provide a basis for future research and decision-making processes which can review this paper's findings and refine the analysis. Equally, the body of information and data on the maturity and scaling of renewable energies – wind and solar in particular – coupled with significant advancements expected in the coming years in off-grid energy options, provide a further avenue for enhancing the analysis presented here, potentially driving down the capital costs of the two renewable energy policy options, which could unlock a greater suite of complementary energy generation options.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2017.04.039.

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Appendix A: MacGregor,J. (2017).Determining an optimal strategy for energy investment in Kazakhstan. Energy Policy 107: 210-224.

Appendix A – Energy generation summary data for each Policy Option

Determining an optimal strategy for energy investment in Kazakhstan

Energy Policy 107: 210-224

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Policy Option 1

	Energy		Generation				Capital costs		Externalities				Externality costs			
	Supply gap (GWh)	Potential supply (GWh)	Coal (GWh)	Gas (GWh)	Large-scale hydro power (GWh)	Wind (GWh)	Capital expenditure Annual (US$)	Operating expenditure Annual (US$)	Carbon emissions (t CO2-e)	NOx emissions (t)	SOx emissions (t)	Water use (kℓ)	Carbon emissions (US$)	NOx emissions (US$)	SOx emissions (US$)	Water use (US$)
2010	-442	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-1,116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	-173	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	-231	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	-492	-	-	-	-	-	-138,000,000	-	-	-	-	-	-	-	-	-
2015	-345	-	-	-	-	-	-322,000,000	-	-	-	-	-	-	-	-	-
2016	-3,449	-	-	-	-	-	-322,000,000	-	-	-	-	-	-	-	-	-
2017	-1,519	-	-	-	-	-	-138,000,000	-	-	-	-	-	-	-	-	-
2018	-73	2,978	2,978	-	-	-	-138,000,000	-14,296,320	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2019	-488	2,978	2,978	-	-	-	-138,000,000	-14,296,320	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2020	-5,683	2,978	2,978	-	-	-	-460,000,000	-14,296,320	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2021	-2,859	2,978	2,978	-	-	-	-1,068,000,000	-14,296,320	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2022	1,424	2,978	2,978	-	-	-	-1,431,000,000	-14,296,320	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2023	4,509	5,957	5,957	-	-	-	-1,596,000,000	-28,592,640	5,361,120	1,608	2,144	12,658,200	118,480,752	1,249,416	1,353,116	12,025,290
2024	9,026	11,866	8,935	2,931	-	-	-1,394,000,000	-54,206,880	9,203,256	2,528	3,217	21,518,940	203,391,958	1,964,256	2,029,675	20,442,993
2025	13,666	14,844	11,914	2,931	-	-	-1,488,000,000	-68,503,200	11,883,816	3,332	4,289	27,848,040	262,632,334	2,588,964	2,706,233	26,455,638
2026	17,567	19,159	14,892	2,931	1,336	-	-1,327,000,000	-85,690,320	14,564,376	4,136	5,361	34,177,140	321,872,710	3,213,672	3,382,791	32,468,283
2027	21,551	22,806	17,870	2,931	2,005	-	-1,080,000,000	-101,432,040	17,244,936	4,940	6,433	40,506,240	381,113,086	3,838,380	4,059,349	38,480,928
2028	25,620	28,715	20,849	5,861	2,005	-	-925,000,000	-127,046,280	21,087,072	5,860	7,505	49,366,980	466,024,291	4,553,220	4,735,907	46,898,631
2029	29,776	34,672	26,806	5,861	2,005	-	-1,214,000,000	-155,638,920	26,448,192	7,468	9,650	62,025,180	584,505,043	5,802,636	6,089,024	58,923,921
2030	30,824	34,672	26,806	5,861	2,005	-	-1,478,000,000	-155,638,920	26,448,192	7,468	9,650	62,025,180	584,505,043	5,802,636	6,089,024	58,923,921
2031	33,698	37,650	29,784	5,861	2,005	-	-1,490,000,000	-169,935,240	29,128,752	8,272	10,722	68,354,280	643,745,419	6,427,344	6,765,582	64,936,566
2032	38,346	40,628	32,762	5,861	2,005	-	-2,417,000,000	-184,231,560	31,809,312	9,076	11,794	74,683,380	702,985,795	7,052,052	7,442,140	70,949,211
2033	43,030	45,611	35,741	5,861	4,009	-	-2,390,000,000	-202,864,080	34,489,872	9,880	12,866	81,012,480	762,226,171	7,676,760	8,118,698	76,961,856
2034	47,752	50,123	38,719	5,861	4,009	1,533	-1,791,000,000	-233,870,100	37,170,432	10,684	13,939	87,341,580	821,466,547	8,301,468	8,795,257	82,974,501
2035	52,511	59,010	44,676	8,792	4,009	1,533	-1,674,000,000	-273,780,660	43,693,128	12,408	16,083	102,531,420	965,618,129	9,641,016	10,148,373	97,404,849
2036	57,309	61,989	47,654	8,792	4,009	1,533	-1,617,000,000	-288,076,980	46,373,688	13,212	17,155	108,860,520	1,024,858,505	10,265,724	10,824,931	103,417,494
2037	62,145	66,303	50,633	8,792	5,345	1,533	-1,569,000,000	-305,264,100	49,054,248	14,016	18,227	115,189,620	1,084,098,881	10,890,432	11,501,489	109,430,139
2038	67,022	72,260	56,590	8,792	5,345	1,533	-1,812,000,000	-333,856,740	54,415,368	15,624	20,372	127,847,820	1,202,579,633	12,139,848	12,854,606	121,455,429
2039	71,938	75,907	59,568	8,792	6,014	1,533	-2,399,000,000	-349,598,460	57,095,928	16,428	21,444	134,176,920	1,261,820,009	12,764,556	13,531,164	127,468,074
2040	76,895	81,816	62,546	11,723	6,014	1,533	-2,784,000,000	-375,212,700	60,938,064	17,348	22,516	143,037,660	1,346,731,214	13,479,396	14,207,722	135,885,777
2041	81,893	85,462	65,525	11,723	6,682	1,533	-2,876,000,000	-390,954,420	63,618,624	18,152	23,588	149,366,760	1,405,971,590	14,104,104	14,884,280	141,898,422
2042	90,548	95,066	74,460	11,723	7,350	1,533	-3,072,000,000	-435,288,780	71,660,304	20,564	26,805	168,354,060	1,583,692,718	15,978,228	16,913,955	159,936,357
2043	99,246	104,622	80,417	14,654	8,018	1,533	-3,072,000,000	-476,644,740	78,183,000	22,288	28,949	183,543,900	1,727,844,300	17,317,776	18,267,071	174,366,705
2044	107,986	111,575	86,374	14,654	8,686	1,862	-2,939,000,000	-510,263,430	83,544,120	23,896	31,094	196,202,100	1,846,325,052	18,567,192	19,620,188	186,391,995
2045	116,771	121,178	95,309	14,654	9,354	1,862	-3,503,000,000	-554,597,790	91,585,800	26,308	34,310	215,189,400	2,024,046,180	20,441,316	21,649,862	204,429,930
2046	125,600	130,734	101,266	17,584	10,023	1,862	-3,401,000,000	-595,953,750	98,108,496	28,032	36,455	230,379,240	2,168,197,762	21,780,864	23,002,979	218,860,278
2047	134,474	138,454	107,222	17,584	10,691	2,957	-2,213,000,000	-637,927,290	103,469,616	29,640	38,599	243,037,440	2,286,678,514	23,030,280	24,356,095	230,885,568
2048	143,394	148,057	116,158	17,584	11,359	2,957	-1,506,000,000	-682,261,650	111,511,296	32,052	41,816	262,024,740	2,464,399,642	24,904,404	26,385,770	248,923,503
2049	152,361	158,281	122,114	20,515	12,695	2,957	-576,000,000	-725,063,010	118,033,992	33,776	43,960	277,214,580	2,608,551,223	26,243,952	27,738,886	263,353,851
2050	161,374	164,895	128,071	20,515	12,695	3,614	-	-760,816,950	123,395,112	35,384	46,105	289,872,780	2,727,031,975	27,493,368	29,092,003	275,379,141

Table A–1: Energy generation summary, Policy Option 1: The Business as usual (BAU) scenario, 2010–2050

The BAU scenario prioritises coal, gas, large-scale hydropower, wind, and small-scale hydropower – in that descending order. By 2050, the supply shortfall will be filled by new investments in 43 coal plants, 7 combined-cycle gas turbines, 19 large-scale hydropower plants, and 33 wind farms. The generation of the supply shortfall is overwhelmingly for coal (78%), and then for gas (12%), large-scale hydropower (8%) and wind (2%).

Policy Option 2

	Energy		**Generation**				**Capital costs**		**Externalities**				**Externality costs**			
	Supply gap	Potential supply	Coal	Gas	Large-scale hydro power	Wind	Capital expenditure	Operating expenditure	Carbon emissions	NOx emissions	SOx emissions	Water use	Carbon emissions	NOx emissions	SOx emissions	Water use
	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	(GWh)	Annual (US$)	Annual (US$)	(t CO2-e)	(t)	(t)	(kℓ)	(US$)	(US$)	(US$)	(US$)
2010	-442	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-1,116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	-173	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	-231	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	-492	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	-345	-	-	-	-	-	-160,000,000	-	-	-	-	-	-	-	-	-
2016	-3,449	-	-	-	-	-	-160,000,000	-	-	-	-	-	-	-	-	-
2017	-1,519	-	-	-	-	-	-160,000,000	-	-	-	-	-	-	-	-	-
2018	-73	329	-	2,931	-	-	-	-11,317,920	1,161,576	116	-	2,531,640	25,670,830	90,132	-	2,405,058
2019	-488	329	-	2,931	-	-	-	-11,317,920	1,161,576	116	-	2,531,640	25,670,830	90,132	-	2,405,058
2020	-5,683	329	-	2,931	-	-	-298,000,000	-11,317,920	1,161,576	116	-	2,531,640	25,670,830	90,132	-	2,405,058
2021	-2,859	329	-	2,931	-	-	-780,000,000	-11,317,920	1,161,576	116	-	2,531,640	25,670,830	90,132	-	2,405,058
2022	1,424	2,081	-	2,931	-	-	-1,240,000,000	-11,317,920	1,161,576	116	-	2,531,640	25,670,830	90,132	-	2,405,058
2023	4,509	5,256	-	5,861	-	-	-1,402,000,000	-22,635,840	2,323,152	232	-	5,063,280	51,341,659	180,264	-	4,810,116
2024	9,026	9,855	2,978	8,792	-	-	-1,242,000,000	-48,250,080	6,165,288	1,152	1,072	13,924,020	136,252,865	895,104	676,558	13,227,819
2025	13,666	16,666	5,957	8,792	-	-	-1,281,000,000	-62,546,400	8,845,848	1,956	2,144	20,253,120	195,493,241	1,519,812	1,353,116	19,240,464
2026	17,567	21,130	11,914	8,792	-	-	-1,086,000,000	-91,139,040	14,206,968	3,564	4,289	32,911,320	313,973,993	2,769,228	2,706,233	31,265,754
2027	21,551	25,751	14,892	8,792	-	-	-1,070,000,000	-105,435,360	16,887,528	4,368	5,361	39,240,420	373,214,369	3,393,936	3,382,791	37,278,399
2028	25,620	30,371	17,870	11,723	-	-	-1,030,000,000	-131,049,600	20,729,664	5,288	6,433	48,101,160	458,125,574	4,108,776	4,059,349	45,696,102
2029	29,776	32,014	20,849	11,723	-	-	-1,343,000,000	-145,345,920	23,410,224	6,092	7,505	54,430,260	517,365,950	4,733,484	4,735,907	51,708,747
2030	30,824	34,992	20,849	11,723	668	-	-1,656,000,000	-146,791,320	23,410,224	6,092	7,505	54,430,260	517,365,950	4,733,484	4,735,907	51,708,747
2031	33,698	36,525	23,827	11,723	668	-	-1,779,000,000	-161,087,640	26,090,784	6,896	8,578	60,759,360	576,606,326	5,358,192	5,412,466	57,721,392
2032	38,346	41,146	26,806	11,723	2,005	-	-1,834,000,000	-178,274,760	28,771,344	7,700	9,650	67,088,460	635,846,702	5,982,900	6,089,024	63,734,037
2033	43,030	45,877	29,784	14,654	2,005	-	-1,617,000,000	-203,889,000	32,613,480	8,620	10,722	75,949,200	720,757,908	6,697,740	6,765,582	72,151,740
2034	47,752	50,607	32,762	14,654	3,341	-	-1,506,000,000	-221,076,120	35,294,040	9,424	11,794	82,278,300	779,998,284	7,322,448	7,442,140	78,164,385
2035	52,511	55,337	38,719	14,654	3,341	-	-1,593,000,000	-249,668,760	40,655,160	11,032	13,939	94,936,500	898,479,036	8,571,864	8,795,257	90,189,675
2036	57,309	60,130	41,698	14,654	4,009	-	-1,834,000,000	-265,410,480	43,335,720	11,836	15,011	101,265,600	957,719,412	9,196,572	9,471,815	96,202,320
2037	62,145	64,970	44,676	17,584	4,009	-	-1,740,000,000	-291,024,720	47,177,856	12,756	16,083	110,126,340	1,042,630,618	9,911,412	10,148,373	104,620,023
2038	67,022	69,919	47,654	17,584	4,677	-	-1,851,000,000	-306,766,440	49,858,416	13,560	17,155	116,455,440	1,101,870,994	10,536,120	10,824,931	110,632,668
2039	71,938	74,868	53,611	17,584	4,677	-	-2,197,000,000	-335,359,080	55,219,536	15,168	19,300	129,113,640	1,220,351,746	11,785,536	12,178,048	122,657,958
2040	76,895	79,927	56,590	17,584	6,014	-	-3,221,000,000	-352,546,200	57,900,096	15,972	20,372	135,442,740	1,279,592,122	12,410,244	12,854,606	128,670,603
2041	81,893	86,097	59,568	20,515	6,014	-	-3,422,000,000	-378,160,440	61,742,232	16,892	21,444	144,303,480	1,364,503,327	13,125,084	13,531,164	137,088,306
2042	90,548	93,817	65,525	20,515	6,682	1,095	-2,738,000,000	-420,133,980	67,103,352	18,500	23,588	156,961,680	1,482,984,079	14,374,500	14,884,280	149,113,596
2043	99,246	103,420	74,460	20,515	7,350	1,095	-3,298,000,000	-464,468,340	75,145,032	20,912	26,805	175,948,980	1,660,705,207	16,248,624	16,913,955	167,151,531
2044	107,986	112,976	80,417	23,446	8,018	1,095	-3,322,000,000	-505,824,300	81,667,728	22,636	28,949	191,138,820	1,804,856,789	17,588,172	18,267,071	181,581,879
2045	116,771	120,477	86,374	23,446	8,686	1,971	-3,082,000,000	-545,410,740	87,028,848	24,244	31,094	203,797,020	1,923,337,541	18,837,588	19,620,188	193,607,169
2046	125,600	130,032	92,330	26,377	9,354	1,971	-2,675,000,000	-586,766,700	93,551,544	25,968	33,238	218,986,860	2,067,489,122	20,177,136	20,973,304	208,037,517
2047	134,474	139,636	101,266	26,377	10,023	1,971	-2,467,000,000	-631,101,060	101,593,224	28,380	36,455	237,974,160	2,245,210,250	22,051,260	23,002,979	226,075,452
2048	143,394	149,192	107,222	29,307	10,691	1,971	-2,277,000,000	-672,457,020	108,115,920	30,104	38,599	253,164,000	2,389,361,832	23,390,808	24,356,095	240,505,800
2049	152,361	156,583	113,179	29,307	11,359	2,738	-1,139,000,000	-710,849,910	113,477,040	31,712	40,744	265,822,200	2,507,842,584	24,640,224	25,709,212	252,531,090
2050	161,374	164,960	119,136	29,307	12,027	4,490	-	-759,984,750	118,838,160	33,320	42,888	278,480,400	2,626,323,336	25,889,640	27,062,328	264,556,380

Table A–2: Energy generation summary, Policy Option 2: The natural gas scenario (15%), 2010–2050

Policy Option 3	Energy		Generation						Capital costs		Externalities				Externality costs			
	Supply gap (GWh)	Potential supply (GWh)	Coal (GWh)	Gas (GWh)	Large-scale hydro power (GWh)	Wind (GWh)	Small-scale hydro power (GWh)	Nuclear (GWh)	Capital expenditure Annual (US$)	Operating expenditure Annual (US$)	Carbon emissions (t CO2-e)	NOx emissions (t)	SOx emissions (t)	Water use (kℓ)	Carbon emissions (US$)	NOx emissions (US$)	SOx emissions (US$)	Water use (US$)
2010	-442	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-1,116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	-173	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	-231	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	-492	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	-345	-	-	-	-	-	-	-	-160,000,000	-	-	-	-	-	-	-	-	-
2016	-3,449	-	-	-	-	-	-	-	-160,000,000	-	-	-	-	-	-	-	-	-
2017	-1,519	-	-	-	-	-	-	-	-160,000,000	-	-	-	-	-	-	-	-	-
2018	-73	329	-	2,931	-	-	-	-	-	-11,317,920	1,161,576	116	-	2,531,640	25,670,830	90,132	-	2,405,058
2019	-488	329	-	2,931	-	-	-	-	-	-11,317,920	1,161,576	116	-	2,531,640	25,670,830	90,132	-	2,405,058
2020	-5,683	329	-	2,931	-	-	-	-	-160,000,000	-11,317,920	1,161,576	116	-	2,531,640	25,670,830	90,132	-	2,405,058
2021	-2,859	329	-	2,931	-	-	-	-	-480,000,000	-11,317,920	1,161,576	116	-	2,531,640	25,670,830	90,132	-	2,405,058
2022	1,424	2,081	-	2,931	-	-	-	-	-640,000,000	-11,317,920	1,161,576	116	-	2,531,640	25,670,830	90,132	-	2,405,058
2023	4,509	5,256	-	5,861	-	-	-	-	-800,000,000	-22,635,840	2,323,152	232	-	5,063,280	51,341,659	180,264	-	4,810,116
2024	9,026	9,855	-	11,723	-	-	-	-	-640,000,000	-45,271,680	4,646,304	464	-	10,126,560	102,683,318	360,528	-	9,620,232
2025	13,666	16,666	-	14,654	-	-	-	-	-800,000,000	-56,589,600	5,807,880	580	-	12,658,200	128,354,148	450,660	-	12,025,290
2026	17,567	21,130	-	20,515	-	-	-	-	-640,000,000	-79,225,440	8,131,032	812	-	17,721,480	179,695,807	630,924	-	16,835,406
2027	21,551	25,751	-	23,446	-	-	-	-	-640,000,000	-90,543,360	9,292,608	928	-	20,253,120	205,366,637	721,056	-	19,240,464
2028	25,620	30,371	-	29,307	-	-	-	-	-618,000,000	-113,179,200	11,615,760	1,160	-	25,316,400	256,708,296	901,320	-	24,050,580
2029	29,776	32,014	-	32,238	-	-	-	-	-918,000,000	-124,497,120	12,777,336	1,276	-	27,848,040	282,379,126	991,452	-	26,455,638
2030	30,824	34,992	-	35,169	-	-	-	-	-1,264,000,000	-135,815,040	13,938,912	1,392	-	30,379,680	308,049,955	1,081,584	-	28,860,696
2031	33,698	36,525	-	38,100	-	-	-	-	-1,402,000,000	-147,132,960	15,100,488	1,508	-	32,911,320	333,720,785	1,171,716	-	31,265,754
2032	38,346	41,146	2,978	38,100	-	-	-	-	-1,218,000,000	-161,429,280	17,781,048	2,312	1,072	39,240,420	392,961,161	1,796,424	676,558	37,278,399
2033	43,030	45,877	8,935	38,100	-	-	-	-	-1,492,000,000	-190,021,920	23,142,168	3,920	3,217	51,898,620	511,441,913	3,045,840	2,029,675	49,303,689
2034	47,752	50,607	11,914	41,030	-	-	-	-	-1,656,000,000	-215,636,160	26,984,304	4,840	4,289	60,759,360	596,353,118	3,760,680	2,706,233	57,721,392
2035	52,511	55,337	14,892	41,030	-	-	-	-	-1,824,000,000	-229,932,480	29,664,864	5,644	5,361	67,088,460	655,593,494	4,385,388	3,382,791	63,734,037
2036	57,309	60,130	17,870	43,961	-	-	-	-	-1,794,000,000	-255,546,720	33,507,000	6,564	6,433	75,949,200	740,504,700	5,100,228	4,059,349	72,151,740
2037	62,145	64,970	20,849	43,961	-	-	-	-	-1,654,000,000	-269,843,040	36,187,560	7,368	7,505	82,278,300	799,745,076	5,724,936	4,735,907	78,164,385
2038	67,022	69,919	23,827	43,961	2,673	-	-	-	-1,540,000,000	-289,920,960	38,868,120	8,172	8,578	88,607,400	858,985,452	6,349,644	5,412,466	84,177,030
2039	71,938	74,868	26,806	46,892	2,673	-	-	-	-1,930,000,000	-315,535,200	42,710,256	9,092	9,650	97,468,140	943,896,658	7,064,484	6,089,024	92,594,733
2040	76,895	79,927	32,762	46,892	2,673	-	-	-	-2,598,000,000	-344,127,840	48,071,376	10,700	11,794	110,126,340	1,062,377,410	8,313,900	7,442,140	104,620,023
2041	81,893	85,305	35,741	46,892	2,673	-	-	-	-3,030,000,000	-358,424,160	50,751,936	11,504	12,866	116,455,440	1,121,617,786	8,938,608	8,118,698	110,632,668
2042	90,548	94,193	41,698	49,823	2,673	-	-	-	-3,087,000,000	-398,334,720	57,274,632	13,228	15,011	131,645,280	1,265,769,367	10,278,156	9,471,815	125,063,016
2043	99,246	103,080	47,654	52,753	2,673	-	-	-	-2,831,000,000	-438,245,280	63,797,328	14,952	17,155	146,835,120	1,409,920,949	11,617,704	10,824,931	139,493,364
2044	107,986	111,710	53,611	52,753	5,345	-	-	-	-3,541,000,000	-472,619,520	69,158,448	16,560	19,300	159,493,320	1,528,401,701	12,867,120	12,178,048	151,518,654
2045	116,771	120,598	59,568	55,684	5,345	-	-	-	-3,598,000,000	-512,530,080	75,681,144	18,284	21,444	174,683,160	1,672,553,282	14,206,668	13,531,164	165,949,002
2046	125,600	129,424	65,525	55,684	6,682	1,533	-	-	-2,875,000,000	-560,723,220	81,042,264	19,892	23,588	187,341,360	1,791,034,034	15,456,084	14,884,280	177,974,292
2047	134,474	138,979	71,482	58,615	7,350	1,533	-	-	-2,413,000,000	-602,079,180	87,564,960	21,616	25,733	202,531,200	1,935,185,616	16,795,632	16,237,397	192,404,640
2048	143,394	148,535	77,438	61,546	8,018	1,533	-	-	-1,281,000,000	-643,435,140	94,087,656	23,340	27,877	217,721,040	2,079,337,198	18,135,180	17,590,513	206,834,988
2049	152,361	158,138	86,374	61,546	8,686	1,533	-	-	-436,000,000	-687,769,500	102,129,336	25,752	31,094	236,708,340	2,257,058,326	20,009,304	19,620,188	224,872,923
2050	161,374	167,026	92,330	64,476	8,686	1,533	-	-	-	-727,680,060	108,652,032	27,476	33,238	251,898,180	2,401,209,907	21,348,852	20,973,304	239,303,271

Table A–3: Energy generation summary, Policy Option 3: The natural gas scenario (30%), 2010–2050

This policy option sees 39% of electricity generated by 22 gas power plants.

Policy Option 4

	Energy		Generation						Capital costs		Externalities				Externality costs			
	Supply gap (GWh)	Potential supply (GWh)	Coal (GWh)	Gas (GWh)	Large-scale hydro power (GWh)	Wind (GWh)	Small-scale hydro power (GWh)	Nuclear (GWh)	Capital expenditure Annual (US$)	Operating expenditure Annual (US$)	Carbon emissions (t CO2-e)	NOx emissions (t)	SOx emissions (t)	Water use (kℓ)	Carbon emissions (US$)	NOx emissions (US$)	SOx emissions (US$)	Water use (US$)
2010	-442	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-1,116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	-173	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	-231	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	-492	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	-345	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2016	-3,449	-	-	-	-	-	-	-	-150,000,000	-	-	-	-	-	-	-	-	-
2017	-1,519	-	-	-	-	-	-	-	-150,000,000	-	-	-	-	-	-	-	-	-
2018	-73	329	-	-	-	329	-	-	-	-3,580,650	-	-	-	-	-	-	-	-
2019	-488	329	-	-	-	329	-	-	-	-3,580,650	-	-	-	-	-	-	-	-
2020	-5,683	329	-	-	-	329	-	-	-800,000,000	-3,580,650	-	-	-	-	-	-	-	-
2021	-2,859	329	-	-	-	329	-	-	-2,388,000,000	-3,580,650	-	-	-	-	-	-	-	-
2022	1,424	2,081	-	-	-	2,081	-	-	-3,872,000,000	-22,677,450	-	-	-	-	-	-	-	-
2023	4,509	5,256	-	-	-	5,256	-	-	-4,470,000,000	-57,290,400	-	-	-	-	-	-	-	-
2024	9,026	9,855	-	-	-	9,855	-	-	-3,208,000,000	-107,419,500	-	-	-	-	-	-	-	-
2025	13,666	16,666	2,978	-	-	13,688	-	-	-2,254,000,000	-163,490,070	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2026	17,567	21,130	2,978	2,931	-	15,221	-	-	-2,098,000,000	-191,517,690	3,842,136	920	1,072	8,860,740	84,911,206	714,840	676,558	8,417,703
2027	21,551	25,751	5,957	2,931	-	16,863	-	-	-2,098,000,000	-223,717,260	6,522,696	1,724	2,144	15,189,840	144,151,582	1,339,548	1,353,116	14,430,348
2028	25,620	30,371	8,935	2,931	-	18,506	-	-	-1,595,000,000	-255,916,830	9,203,256	2,528	3,217	21,518,940	203,391,958	1,964,256	2,029,675	20,442,993
2029	29,776	32,014	8,935	2,931	-	20,148	-	-	-1,214,000,000	-273,820,080	9,203,256	2,528	3,217	21,518,940	203,391,958	1,964,256	2,029,675	20,442,993
2030	30,824	34,992	11,914	2,931	-	20,148	-	-	-1,406,000,000	-288,116,400	11,883,816	3,332	4,289	27,848,040	262,632,334	2,588,964	2,706,233	26,455,638
2031	33,698	38,299	14,892	2,931	-	20,477	-	-	-1,574,000,000	-305,993,370	14,564,376	4,136	5,361	34,177,140	321,872,710	3,213,672	3,382,791	32,468,283
2032	38,346	41,606	17,870	2,931	-	20,805	-	-	-1,631,000,000	-323,870,340	17,244,936	4,940	6,433	40,506,240	381,113,086	3,838,380	4,059,349	38,480,928
2033	43,030	45,691	20,849	2,931	668	21,243	-	-	-1,878,000,000	-344,386,260	19,925,496	5,744	7,505	46,835,340	440,353,462	4,463,088	4,735,907	44,493,573
2034	47,752	51,928	23,827	5,861	668	21,572	-	-	-1,930,000,000	-373,581,150	23,767,632	6,664	8,578	55,696,080	525,264,667	5,177,928	5,412,466	52,911,276
2035	52,511	55,345	26,806	5,861	668	22,010	-	-	-1,893,000,000	-392,651,670	26,448,192	7,468	9,650	62,025,180	584,505,043	5,802,636	6,089,024	58,923,921
2036	57,309	61,740	32,762	5,861	668	22,448	-	-	-1,862,000,000	-426,018,510	31,809,312	9,076	11,794	74,683,380	702,985,795	7,052,052	7,442,140	70,949,211
2037	62,145	65,156	35,741	5,861	668	22,886	-	-	-2,006,000,000	-445,089,030	34,489,872	9,880	12,866	81,012,480	762,226,171	7,676,760	8,118,698	76,961,856
2038	67,022	69,799	38,719	5,861	2,005	23,214	-	-	-2,372,000,000	-465,856,800	37,170,432	10,684	13,939	87,341,580	821,466,547	8,301,468	8,795,257	82,974,501
2039	71,938	76,146	41,698	8,792	2,005	23,652	-	-	-2,663,000,000	-496,245,240	41,012,568	11,604	15,011	96,202,320	906,377,753	9,016,308	9,471,815	91,392,204
2040	76,895	80,231	44,676	8,792	2,673	24,090	-	-	-2,976,000,000	-516,761,160	43,693,128	12,408	16,083	102,531,420	965,618,129	9,641,016	10,148,373	97,404,849
2041	81,893	86,626	50,633	8,792	2,673	24,528	-	-	-3,036,000,000	-550,128,000	49,054,248	14,016	18,227	115,189,620	1,084,098,881	10,890,432	11,501,489	109,430,139
2042	90,548	94,357	56,590	8,792	4,009	24,966	-	-	-3,249,000,000	-586,385,640	54,415,368	15,624	20,372	127,847,820	1,202,579,633	12,139,848	12,854,606	121,455,429
2043	99,246	103,682	62,546	11,723	4,009	25,404	-	-	-3,330,000,000	-631,070,400	60,938,064	17,348	22,516	143,037,660	1,346,731,214	13,479,396	14,207,722	135,885,777
2044	107,986	111,523	68,503	11,723	5,345	25,952	-	-	-3,234,000,000	-668,521,590	66,299,184	18,956	24,661	155,695,860	1,465,211,966	14,728,812	15,560,839	147,911,067
2045	116,771	120,896	77,438	11,723	5,345	26,390	-	-	-3,330,000,000	-716,184,750	74,340,864	21,368	27,877	174,683,160	1,642,933,094	16,602,936	17,590,513	165,949,002
2046	125,600	130,222	83,395	14,654	5,345	26,828	-	-	-3,249,000,000	-760,869,510	80,863,560	23,092	30,022	189,873,000	1,787,084,676	17,942,484	18,943,630	180,379,350
2047	134,474	138,731	89,352	14,654	7,350	27,375	-	-	-2,634,000,000	-799,766,100	86,224,680	24,700	32,166	202,531,200	1,905,565,428	19,191,900	20,296,746	192,404,640
2048	143,394	147,775	98,287	14,654	7,350	27,485	-	-	-1,768,000,000	-843,848,610	94,266,360	27,112	35,383	221,518,500	2,083,286,556	21,066,024	22,326,421	210,442,575
2049	152,361	157,101	104,244	17,584	7,350	27,923	-	-	-602,000,000	-888,533,370	100,789,056	28,836	37,527	236,708,340	2,227,438,138	22,405,572	23,679,537	224,872,923
2050	161,374	164,832	110,201	17,584	8,686	28,361	-	-	-	-924,791,010	106,150,176	30,444	39,671	249,366,540	2,345,918,890	23,654,988	25,032,653	236,898,213

Table A–4: Energy generation summary, Policy Option 4: The renewable energy scenario (15%), 2010–2050

This policy option favours renewable energy and entails the building of 262 wind farms by 2050, in addition to 15 large-scale hydropower plants, 37 coal plants and 6 gas plants. In sum, renewable energy will account for 22% of the electricity generation mix, with coal accounting for 66% and gas for 11%.

Policy Option 5

	Energy		Generation						Capital costs		Externalities				Externality costs			
	Supply gap (GWh)	Potential supply (GWh)	Coal (GWh)	Gas (GWh)	Large-scale hydro power (GWh)	Wind (GWh)	Small-scale hydro power (GWh)	Nuclear (GWh)	Capital expenditure Annual (US$)	Operating expenditure Annual (US$)	Carbon emissions (t CO2-e)	NOx emissions (t)	SOx emissions (t)	Water use (kℓ)	Carbon emissions (US$)	NOx emissions (US$)	SOx emissions (US$)	Water use (US$)
2010	-442	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-1,116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	-173	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	-231	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	-492	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	-345	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2016	-3,449	-	-	-	-	-	-	-	-150,000,000	-	-	-	-	-	-	-	-	-
2017	-1,519	-	-	-	-	-	-	-	-150,000,000	-	-	-	-	-	-	-	-	-
2018	-73	329	-	-	-	329	-	-	-	-3,580,650	-	-	-	-	-	-	-	-
2019	-488	329	-	-	-	329	-	-	-	-3,580,650	-	-	-	-	-	-	-	-
2020	-5,683	329	-	-	-	329	-	-	-800,000,000	-3,580,650	-	-	-	-	-	-	-	-
2021	-2,859	329	-	-	-	329	-	-	-2,388,000,000	-3,580,650	-	-	-	-	-	-	-	-
2022	1,424	2,081	-	-	-	2,081	-	-	-3,872,000,000	-22,677,450	-	-	-	-	-	-	-	-
2023	4,509	5,256	-	-	-	5,256	-	-	-4,470,000,000	-57,290,400	-	-	-	-	-	-	-	-
2024	9,026	9,855	-	-	-	9,855	-	-	-3,208,000,000	-107,419,500	-	-	-	-	-	-	-	-
2025	13,666	16,666	2,978	-	-	13,688	-	-	-2,254,000,000	-163,490,070	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2026	17,567	21,130	2,978	2,931	-	15,221	-	-	-2,098,000,000	-191,517,690	3,842,136	920	1,072	8,860,740	84,911,206	714,840	676,558	8,417,703
2027	21,551	25,751	5,957	2,931	-	16,863	-	-	-1,960,000,000	-223,717,260	6,522,696	1,724	2,144	15,189,840	144,151,582	1,339,548	1,353,116	14,430,348
2028	25,620	30,371	8,935	2,931	-	18,506	-	-	-1,210,000,000	-255,916,830	9,203,256	2,528	3,217	21,518,940	203,391,958	1,964,256	2,029,675	20,442,993
2029	29,776	32,014	8,935	2,931	-	20,148	-	-	-1,298,000,000	-273,820,080	9,203,256	2,528	3,217	21,518,940	203,391,958	1,964,256	2,029,675	20,442,993
2030	30,824	34,992	11,914	2,931	-	20,148	-	-	-2,232,000,000	-288,116,400	11,883,816	3,332	4,289	27,848,040	262,632,334	2,588,964	2,706,233	26,455,638
2031	33,698	36,525	11,914	2,931	-	21,681	-	-	-2,470,000,000	-304,826,100	11,883,816	3,332	4,289	27,848,040	262,632,334	2,588,964	2,706,233	26,455,638
2032	38,346	41,146	14,892	2,931	-	23,324	-	-	-2,382,000,000	-337,025,670	14,564,376	4,136	5,361	34,177,140	321,872,710	3,213,672	3,382,791	32,468,283
2033	43,030	45,877	17,870	2,931	-	25,076	-	-	-2,358,000,000	-370,418,790	17,244,936	4,940	6,433	40,506,240	381,113,086	3,838,380	4,059,349	38,480,928
2034	47,752	50,607	20,849	2,931	-	26,828	-	-	-2,408,000,000	-403,811,910	19,925,496	5,744	7,505	46,835,340	440,353,462	4,463,088	4,735,907	44,493,573
2035	52,511	55,337	23,827	2,931	-	28,580	-	-	-2,642,000,000	-437,205,030	22,606,056	6,548	8,578	53,164,440	499,593,838	5,087,796	5,412,466	50,506,218
2036	57,309	60,130	23,827	5,861	-	30,441	-	-	-2,985,000,000	-468,813,300	23,767,632	6,664	8,578	55,696,080	525,264,667	5,177,928	5,412,466	52,911,276
2037	62,145	64,970	26,806	5,861	-	32,303	-	-	-3,302,000,000	-503,399,970	26,448,192	7,468	9,650	62,025,180	584,505,043	5,802,636	6,089,024	58,923,921
2038	67,022	69,919	29,784	5,861	-	34,274	-	-	-3,516,000,000	-539,180,190	29,128,752	8,272	10,722	68,354,280	643,745,419	6,427,344	6,765,582	64,936,566
2039	71,938	74,868	32,762	5,861	-	36,245	-	-	-3,838,000,000	-574,960,410	31,809,312	9,076	11,794	74,683,380	702,985,795	7,052,052	7,442,140	70,949,211
2040	76,895	79,927	35,741	5,861	-	38,325	-	-	-3,989,000,000	-611,934,180	34,489,872	9,880	12,866	81,012,480	762,226,171	7,676,760	8,118,698	76,961,856
2041	81,893	85,349	35,741	5,861	3,341	40,406	-	-	-4,000,000,000	-641,838,630	34,489,872	9,880	12,866	81,012,480	762,226,171	7,676,760	8,118,698	76,961,856
2042	90,548	96,426	41,698	8,792	3,341	42,596	-	-	-3,815,000,000	-705,620,190	41,012,568	11,604	15,011	96,202,320	906,377,753	9,016,308	9,471,815	91,392,204
2043	99,246	104,573	47,654	8,792	3,341	44,786	-	-	-3,985,000,000	-758,083,830	46,373,688	13,212	17,155	108,860,520	1,024,858,505	10,265,724	10,824,931	103,417,494
2044	107,986	112,829	53,611	8,792	3,341	47,085	-	-	-4,887,666,667	-811,741,020	51,734,808	14,820	19,300	121,518,720	1,143,339,257	11,515,140	12,178,048	115,442,784
2045	116,771	121,086	59,568	8,792	3,341	49,385	-	-	-5,219,333,333	-865,398,210	57,095,928	16,428	21,444	134,176,920	1,261,820,009	12,764,556	13,531,164	127,468,074
2046	125,600	129,404	62,546	11,723	3,341	51,794	-	-	-5,078,333,333	-917,270,550	60,938,064	17,348	22,516	143,037,660	1,346,731,214	13,479,396	14,207,722	135,885,777
2047	134,474	138,766	68,503	11,723	4,009	52,779	-	1,752	-4,492,333,333	-973,818,540	66,299,184	18,956	24,661	161,652,660	1,465,211,966	14,728,812	15,560,839	153,570,027
2048	143,394	147,691	74,460	11,723	4,677	53,327	-	3,504	-2,937,666,667	-1,025,592,330	71,660,304	20,564	26,805	180,267,660	1,583,692,718	15,978,228	16,913,955	171,254,277
2049	152,361	157,185	80,417	11,723	5,345	54,093	-	5,606	-1,264,666,667	-1,082,906,820	77,021,424	22,172	28,949	200,074,020	1,702,173,470	17,227,644	18,267,071	190,070,319
2050	161,374	165,503	83,395	14,654	5,345	54,750	-	7,358	-	-1,131,450,360	80,863,560	23,092	30,022	214,891,560	1,787,084,676	17,942,484	18,943,630	204,146,982

Table A–5: Energy generation summary, Policy Option 5: The renewable energy scenario (30%), 2010–2050

This option features 42% of the generation capacity by 2050 being from renewable sources, with 33% from wind alone.

Policy Option 6

	Energy		Generation					Capital costs		Externalities				Externality costs			
	Supply gap (GWh)	Potential supply (GWh)	Coal (GWh)	Gas (GWh)	Large-scale hydropower (GWh)	Wind (GWh)	Small-scale hydropower (GWh)	Capital expenditure Annual (US$)	Operating expenditure Annual (US$)	Carbon emissions (t CO2-e)	NOx emissions (t)	SOx emissions (t)	Water use (kℓ)	Carbon emissions (US$)	NOx emissions (US$)	SOx emissions (US$)	Water use (US$)
2010	-442	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	-1,116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	-173	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	-231	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	-492	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	-345	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2016	-3,449	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2017	-1,519	-	-	-	-	-	-	-160,000,000	-	-	-	-	-	-	-	-	-
2018	-73	329	-	-	-	-	315	-	-1,608,336	-	-	-	-	-	-	-	-
2019	-488	329	-	-	-	-	315	-189,000,000	-1,608,336	-	-	-	-	-	-	-	-
2020	-5,683	329	-	-	-	-	315	-873,000,000	-1,608,336	-	-	-	-	-	-	-	-
2021	-2,859	329	-	-	-	-	315	-2,784,000,000	-1,608,336	-	-	-	-	-	-	-	-
2022	1,424	2,081	-	-	-	-	1,971	-4,287,000,000	-10,052,100	-	-	-	-	-	-	-	-
2023	4,509	5,256	-	-	-	-	4,928	-4,266,000,000	-25,130,250	-	-	-	-	-	-	-	-
2024	9,026	9,855	-	-	1,971	-	7,529	-2,593,000,000	-42,735,222	-	-	-	-	-	-	-	-
2025	13,666	16,666	-	-	6,570	-	7,529	-2,129,000,000	-52,853,022	-	-	-	-	-	-	-	-
2026	17,567	21,130	-	-	10,512	-	7,529	-1,631,000,000	-61,525,422	-	-	-	-	-	-	-	-
2027	21,551	25,751	2,978	-	12,483	-	7,529	-1,421,000,000	-80,157,942	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2028	25,620	30,371	5,957	-	13,140	-	7,529	-1,379,000,000	-95,899,662	5,361,120	1,608	2,144	12,658,200	118,480,752	1,249,416	1,353,116	12,025,290
2029	29,776	32,014	8,935	-	14,454	-	7,529	-1,584,000,000	-113,086,782	8,041,680	2,412	3,217	18,987,300	177,721,128	1,874,124	2,029,675	18,037,935
2030	30,824	34,992	8,935	2,931	15,111	-	7,529	-1,601,000,000	-125,850,102	9,203,256	2,528	3,217	21,518,940	203,391,958	1,964,256	2,029,675	20,442,993
2031	33,698	36,525	11,914	2,931	15,111	-	7,529	-1,881,000,000	-140,146,422	11,883,816	3,332	4,289	27,848,040	262,632,334	2,588,964	2,706,233	26,455,638
2032	38,346	41,146	14,892	2,931	16,425	-	7,529	-2,002,000,000	-157,333,542	14,564,376	4,136	5,361	34,177,140	321,872,710	3,213,672	3,382,791	32,468,283
2033	43,030	45,877	17,870	2,931	17,082	-	7,529	-2,002,000,000	-173,075,262	17,244,936	4,940	6,433	40,506,240	381,113,086	3,838,380	4,059,349	38,480,928
2034	47,752	50,607	20,849	5,861	17,739	-	7,529	-1,658,000,000	-200,134,902	21,087,072	5,860	7,505	49,366,980	466,024,291	4,553,220	4,735,907	46,898,631
2035	52,511	55,337	26,806	5,861	18,396	-	7,529	-1,520,000,000	-230,172,942	26,448,192	7,468	9,650	62,025,180	584,505,043	5,802,636	6,089,024	58,923,921
2036	57,309	60,130	29,784	5,861	19,053	-	7,529	-1,583,000,000	-245,914,662	29,128,752	8,272	10,722	68,354,280	643,745,419	6,427,344	6,765,582	64,936,566
2037	62,145	64,970	32,762	5,861	19,710	-	7,529	-2,362,000,000	-261,656,382	31,809,312	9,076	11,794	74,683,380	702,985,795	7,052,052	7,442,140	70,949,211
2038	67,022	69,919	35,741	5,861	20,367	-	7,529	-2,789,000,000	-277,398,102	34,489,872	9,880	12,866	81,012,480	762,226,171	7,676,760	8,118,698	76,961,856
2039	71,938	74,868	38,719	5,861	21,024	876	7,529	-2,813,000,000	-302,688,222	37,170,432	10,684	13,939	87,341,580	821,466,547	8,301,468	8,795,257	82,974,501
2040	76,895	79,927	41,698	8,792	21,681	876	7,529	-2,896,000,000	-329,747,862	41,012,568	11,604	15,011	96,202,320	906,377,753	9,016,308	9,471,815	91,392,204
2041	81,893	87,847	47,654	8,792	22,995	876	7,529	-3,074,000,000	-361,231,302	46,373,688	13,212	17,155	108,860,520	1,024,858,505	10,265,724	10,824,931	103,417,494
2042	90,548	94,461	53,611	8,792	23,652	876	7,529	-3,194,000,000	-391,269,342	51,734,808	14,820	19,300	121,518,720	1,143,339,257	11,515,140	12,178,048	115,442,784
2043	99,246	101,731	59,568	8,792	24,966	876	7,529	-3,360,000,000	-422,752,782	57,095,928	16,428	21,444	134,176,920	1,261,820,009	12,764,556	13,531,164	127,468,074
2044	107,986	111,933	65,525	11,723	26,280	876	7,529	-3,114,000,000	-465,554,142	63,618,624	18,152	23,588	149,366,760	1,405,971,590	14,104,104	14,884,280	141,898,422
2045	116,771	119,532	71,482	11,723	27,594	1,205	7,529	-2,627,000,000	-500,618,232	68,979,744	19,760	25,733	162,024,960	1,524,452,342	15,353,520	16,237,397	153,923,712
2046	125,600	129,125	80,417	11,723	28,251	1,205	7,529	-3,158,000,000	-544,952,592	77,021,424	22,172	28,949	181,012,260	1,702,173,470	17,227,644	18,267,071	171,961,647
2047	134,474	139,326	86,374	14,654	29,565	1,205	7,529	-2,596,000,000	-587,753,952	83,544,120	23,896	31,094	196,202,100	1,846,325,052	18,567,192	19,620,188	186,391,995
2048	143,394	146,487	92,330	14,654	29,565	2,409	7,529	-1,218,000,000	-629,475,642	88,905,240	25,504	33,238	208,860,300	1,964,805,804	19,816,608	20,973,304	198,417,285
2049	152,361	158,353	101,266	17,584	29,565	2,409	7,529	-276,000,000	-683,682,522	98,108,496	28,032	36,455	230,379,240	2,168,197,762	21,780,864	23,002,979	218,860,278
2050	161,374	164,310	107,222	17,584	29,565	2,409	7,529	-	-712,275,162	103,469,616	29,640	38,599	243,037,440	2,286,678,514	23,030,280	24,356,095	230,885,568

Table A–6: Energy generation summary, Policy Option 6: The hydropower scenario, 2010–2050

This policy option has 191 small- and medium-scale hydropower plants as well as 45 large-scale hydropower plants, which together will cost US$30.82 billion to build to generate 23% of electricity by 2050.

Policy Option 7

	Energy		Generation						Capital costs		Externalities				Externality costs			
	Supply gap (GWh)	Potential supply (GWh)	Coal (GWh)	Gas (GWh)	Large-scale hydropower (GWh)	Wind (GWh)	Small-scale hydropower (GWh)	Nuclear (GWh)	Capital expenditure Annual (US$)	Operating expenditure Annual (US$)	Carbon emissions (t CO2-e)	NOx emissions (t)	SOx emissions (t)	Water use (kℓ)	Carbon emissions (US$)	NOx emissions (US$)	SOx emissions (US$)	Water use (US$)
2010	-442	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-
2011	-1,116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	-173	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	-231	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	-492	-	-	-	-	-	-	-	-138,000,000	-	-	-	-	-	-	-	-	-
2015	-345	-	-	-	-	-	-	-	-322,000,000	-	-	-	-	-	-	-	-	-
2016	-3,449	-	-	-	-	-	-	-	-322,000,000	-	-	-	-	-	-	-	-	-
2017	-1,519	-	-	-	-	-	-	-	-138,000,000	-	-	-	-	-	-	-	-	-
2018	-73	329	2,978	-	-	-	-	-	-	-14,296,320	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2019	-488	329	2,978	-	-	-	-	-	-138,000,000	-14,296,320	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2020	-5,683	329	2,978	-	-	-	-	-	-985,000,000	-14,296,320	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2021	-2,859	329	2,978	-	-	-	-	-	-2,004,000,000	-14,296,320	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2022	1,424	2,081	2,978	-	-	-	-	-	-2,308,000,000	-14,296,320	2,680,560	804	1,072	6,329,100	59,240,376	624,708	676,558	6,012,645
2023	4,509	5,256	5,957	-	-	-	-	-	-1,958,000,000	-28,592,640	5,361,120	1,608	2,144	12,658,200	118,480,752	1,249,416	1,353,116	12,025,290
2024	9,026	9,855	8,935	2,931	-	-	-	-	-1,307,000,000	-54,206,880	9,203,256	2,528	3,217	21,518,940	203,391,958	1,964,256	2,029,675	20,442,993
2025	13,666	16,666	8,935	2,931	-	-	-	7,884	-920,000,000	-101,510,880	9,203,256	2,528	3,217	48,324,540	203,391,958	1,964,256	2,029,675	45,908,313
2026	17,567	21,130	11,914	2,931	-	-	-	7,884	-782,000,000	-115,807,200	11,883,816	3,332	4,289	54,653,640	262,632,334	2,588,964	2,706,233	51,920,958
2027	21,551	25,751	14,892	2,931	-	-	-	7,884	-1,283,000,000	-130,103,520	14,564,376	4,136	5,361	60,982,740	321,872,710	3,213,672	3,382,791	57,933,603
2028	25,620	30,371	17,870	2,931	-	-	-	7,884	-1,958,000,000	-144,399,840	17,244,936	4,940	6,433	67,311,840	381,113,086	3,838,380	4,059,349	63,946,248
2029	29,776	32,014	20,849	2,931	-	-	-	7,884	-2,492,000,000	-158,696,160	19,925,496	5,744	7,505	73,640,940	440,353,462	4,463,088	4,735,907	69,958,893
2030	30,824	34,992	20,849	5,861	-	-	-	7,884	-2,120,000,000	-170,014,080	21,087,072	5,860	7,505	76,172,580	466,024,291	4,553,220	4,735,907	72,363,951
2031	33,698	36,525	23,827	5,861	-	-	-	7,884	-1,445,000,000	-184,310,400	23,767,632	6,664	8,578	82,501,680	525,264,667	5,177,928	5,412,466	78,376,596
2032	38,346	41,146	26,806	5,861	-	-	-	15,768	-920,000,000	-245,910,720	26,448,192	7,468	9,650	115,636,380	584,505,043	5,802,636	6,089,024	109,854,561
2033	43,030	45,877	29,784	5,861	-	-	-	15,768	-983,000,000	-260,207,040	29,128,752	8,272	10,722	121,965,480	643,745,419	6,427,344	6,765,582	115,867,206
2034	47,752	50,607	32,762	5,861	-	-	-	15,768	-1,413,000,000	-274,503,360	31,809,312	9,076	11,794	128,294,580	702,985,795	7,052,052	7,442,140	121,879,851
2035	52,511	55,337	35,741	5,861	-	-	-	15,768	-2,223,000,000	-288,799,680	34,489,872	9,880	12,866	134,623,680	762,226,171	7,676,760	8,118,698	127,892,496
2036	57,309	60,130	38,719	5,861	-	-	-	15,768	-2,982,000,000	-303,096,000	37,170,432	10,684	13,939	140,952,780	821,466,547	8,301,468	8,795,257	133,905,141
2037	62,145	64,970	41,698	8,792	-	-	-	15,768	-2,965,000,000	-328,710,240	41,012,568	11,604	15,011	149,813,520	906,377,753	9,016,308	9,471,815	142,322,844
2038	67,022	69,919	44,676	8,792	668	-	-	15,768	-2,447,000,000	-344,451,960	43,693,128	12,408	16,083	156,142,620	965,618,129	9,641,016	10,148,373	148,335,489
2039	71,938	74,868	47,654	8,792	2,673	-	-	15,768	-2,094,000,000	-363,084,480	46,373,688	13,212	17,155	162,471,720	1,024,858,505	10,265,724	10,824,931	154,348,134
2040	76,895	79,927	50,633	8,792	2,673	-	-	23,652	-2,819,000,000	-424,684,800	49,054,248	14,016	18,227	195,606,420	1,084,098,881	10,890,432	11,501,489	185,826,099
2041	81,893	88,728	53,611	8,792	2,673	-	-	23,652	-3,620,000,000	-438,981,120	51,734,808	14,820	19,300	201,935,520	1,143,339,257	11,515,140	12,178,048	191,838,744
2042	90,548	94,685	59,568	8,792	2,673	-	-	23,652	-3,786,000,000	-467,573,760	57,095,928	16,428	21,444	214,593,720	1,261,820,009	12,764,556	13,531,164	203,864,034
2043	99,246	103,572	65,525	11,723	2,673	-	-	23,652	-3,670,000,000	-507,484,320	63,618,624	18,152	23,588	229,783,560	1,405,971,590	14,104,104	14,884,280	218,294,382
2044	107,986	111,534	71,482	11,723	4,677	-	-	23,652	-3,542,000,000	-540,413,160	68,979,744	19,760	25,733	242,441,760	1,524,452,342	15,353,520	16,237,397	230,319,672
2045	116,771	122,396	74,460	11,723	4,677	-	-	31,536	-3,887,000,000	-602,013,480	71,660,304	20,564	26,805	275,576,460	1,583,692,718	15,978,228	16,913,955	261,797,637
2046	125,600	131,284	80,417	14,654	4,677	-	-	31,536	-4,072,000,000	-641,924,040	78,183,000	22,288	28,949	290,766,300	1,727,844,300	17,317,776	18,267,071	276,227,985
2047	134,474	138,577	86,374	14,654	6,014	-	-	31,536	-4,683,000,000	-673,407,480	83,544,120	23,896	31,094	303,424,500	1,846,325,052	18,567,192	19,620,188	288,253,275
2048	143,394	147,874	92,330	14,654	9,354	-	-	31,536	-3,293,000,000	-709,227,120	88,905,240	25,504	33,238	316,082,700	1,964,805,804	19,816,608	20,973,304	300,278,565
2049	152,361	156,580	98,287	14,654	10,023	2,081	-	31,536	-961,000,000	-761,942,610	94,266,360	27,112	35,383	328,740,900	2,083,286,556	21,066,024	22,326,421	312,303,855
2050	161,374	173,352	104,244	17,584	10,023	2,081	-	39,420	-	-849,157,170	100,789,056	28,836	37,527	370,736,340	2,227,438,138	22,405,572	23,679,537	352,199,523

Table A–7: Energy generation summary, Policy Option 7: The nuclear scenario, 2010–2050

This option includes building five nuclear power plants by 2050, which will account for 23% of electricity generation.

Paper II

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Fuelwood scarcity, energy substitution, and rural livelihoods in Namibia*

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ABSTRACT. In Namibia, as in many parts of Africa, households are highly dependent on forest resources for their livelihoods, including energy needs. Using data originally collected for Namibia's forest resource accounts and insights from a non-separable household model, this paper estimates household fuelwood demand. Specifically, the factors underlying the substitution between fuelwood collected from open access forest resources, cow dung, and fuelwood purchased from the market are analysed. Heckman two-step estimates show that households respond to economic scarcity, as measured by the opportunity costs of collecting fuelwood, by reducing energy consumption slightly more than by increasing labour input to collection. There is limited evidence for substitution from fuelwood to other energy sources, particularly with declining availability of forest stocks. Market participants may be more sensitive to price changes than non-participants. All estimated elasticities are low, similar to those observed in previous studies.

1. Introduction

According to FAOStat data (2007), more than half of global wood production is classified as non-industrial roundwood, mostly used as fuelwood for energy production. Wood and charcoal are the dominant energy sources for cooking and heating for over two billion people, mainly rural households in developing countries. Fuelwood collection in rural areas can potentially contribute to deforestation and forest degradation, although the extent to which this occurs depends on sources of supply and demand, the nature of fuelwood and charcoal markets and household behaviour (Arnold *et al.*, 2003). There is a two-way relationship between fuelwood

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collection and forest degradation. Fuelwood demand can cause degradation to the extent that collection exceeds sustainable yield, while degradation can lead to a situation of physical, fuelwood scarcity (Heltberg *et al.*, 2000). Dependence on forests for energy implies that physical scarcity can impact on household welfare.

Fuelwood, while 'free' financially, incurs opportunity costs in the form of collection labour time (Amacher *et al.*, 1993). Higher opportunity costs or shadow prices imply increasing economic scarcity. Economic scarcity is household-specific and dependent on a wide range of factors including physical scarcity, household endowments, and institutions for natural resource management (Heltberg *et al.*, 2000). It is perhaps a better measure of 'scarcity' than purely physical measures of resource stocks due to being a better predictor of household behaviour and, hence, pressure on resource stocks (Amacher *et al.*, 1996). Potential impacts of increasing economic scarcity include constraints on resource degradation, inducements to improved energy efficiency, and substitution to alternatives such as crop residues or animal dung.[1]

Empirical evidence about the consumption and production of fuelwood in rural households has shown that fuelwood consumption tends to be own-price inelastic (Cooke *et al.*, 2008). While its consumption declines with increases in its price (market or shadow), household expenditures increase, often in the form of increased labour allocated to collection (Kumar and Hotchkiss, 1988; Cooke, 1998a,b). With higher incomes households may switch to marketed energy sources such as kerosene or coal (Hyde and Köhlin, 2000; Chen *et al.*, 2006).

In 2004, data on household forest use were collected by Namibia's Ministry of Environment and Tourism (MET), in collaboration with the Institute for Environment and Development (IIED).[2] Similar to much of Africa, Namibia remains mired in poverty, with up to 90 per cent of a rising population dependent on fuelwood and other biomass for their energy needs (FAO, 1997, 2007). The study's objective was to develop Namibia's physical and economic forest resource accounts (see Barnes *et al.*, 2005; Nhuleipo *et al.*, 2005). Forest stocks were addressed by the former, while the latter measured the economic value of direct forest uses, including non-marketed goods such as fuelwood and poles (for buildings). Variation in levels of forest stocks was observed, ranging from relative physical resource abundance to scarcity. The raw data also permitted the estimation of the household demand for fuelwood in Namibia, which is the focus of this paper.

As is usual in much of the developing world, many Namibian households collect fuelwood for internal consumption. A household's primary input to fuelwood collection is labour so its shadow price is defined by the opportunity cost of the time spent collecting. Since livelihoods in Namibia are mainly farm-based, the opportunity cost of labour can be measured

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[1] Note that crop residues and dung are also important farm inputs in many poor households in Asia and Africa. Using these for fuel instead of manure can impact on soil fertility (Amacher *et al.*, 1999; Heltberg *et al.*, 2000).

[2] See: www.met.gov. na/; www.iied.org/.

as the marginal product of agricultural labour. A household is better-off choosing self-sufficiency in fuelwood if its subjective price falls inside a 'price band' for fuelwood, i.e. between market purchase and sales prices. Wide price bands for factors of production and produced goods reveal market failures (Sadoulet and de Janvry, 1995). Missing markets for fuelwood suggests the use of a non-separable or non-recursive household model, where all production, consumption, and labour time decisions are decided simultaneously (Hyde and Köhlin, 2000).

Additional to fuelwood collectors, the Namibian sample contains a number of collectors that also purchase fuelwood from the market. This implies that households sometimes switch to buying fuelwood when its shadow price exceeds the purchase price, i.e. households are sometimes better-off participating in the market instead of collecting fuelwood, and vice versa. Guided by the model, we empirically estimate household demand for fuelwood and the factors underlying substitution between collected and purchased fuelwood, and cattle dung. In order to deal with potential selectivity bias in the sample due to the presence of different price regimes among households, we derive the model parameters using maximum likelihood estimates (MLE) of the Heckman two-step estimator. Furthermore, to estimate fuelwood collection and consumption, we use a novel three-stage approach in order to control both for sample selection bias and endogeneity problems.

We find that with higher collection times, Namibian households reduce fuelwood consumption just slightly more than by increasing their labour allocation to fuelwood collection, although the difference is negligible. There is limited evidence for substitution to dung, particularly where there is a lower availability of forest stock. Households do not respond to economic scarcity by purchasing more fuelwood from the market. Market participants may be more price sensitive than non-participants. The paper joins a relatively small, empirical literature on this topic, one that is dominated by South Asian cases (see Cooke *et al.*, 2008). In line with these studies, fuelwood demand among households in Namibia is inelastic. By contrast, in one of few studies undertaken in Africa, Mekonnen (1998) found fuelwood consumption in the more arid uplands of Ethiopia to be relatively less inelastic. Mekonnen also found that fuelwood and dung are used as energy complements instead of substitutes for cooking.

The paper begins with a presentation of the background to the study area and data collection along with some results of the resource accounting exercise, in section 2. A conceptual model for the supply and demand of fuel is outlined in section 3. In section 4, the method of empirical application is described, with the results discussed in section 5. Conclusions and policy implications are presented in section 6.

2. Background

2.1. Background to Namibia's forests and study area

Situated on the south-west coast of Africa, Namibia's 7.7 million hectares of forests, 9 per cent of the country's land area, are mainly contained in woodlands and savannas (shrublands). These increase in density from the extremely sparse, arid desert environment in the south towards the semi-arid north-east. Between 1990 and 2005, Namibia's forest area declined by 1.1 per cent (United Nations, 2007). In common with much of Africa, the country contains relatively little 'forest' in the conventional sense.[3] Forest resources are defined in this paper as all woody plants that occur in the woodlands and savannas.

Per capita GDP of N$46,000 (US$7,400)[4] masks acute income inequality and widespread poverty. An estimated 90 per cent of the population lives on less than US$2 per day, with high dependence on natural resources for livelihoods. Fuelwood is typically gathered from land classified as 'public forest'. Namibia's forest resources are, in effect, *de facto* open access. Relatively little was known about forest utilization rates and the direct use values derived by local people, particularly those that are unmarketed or traded in the informal sector. Namibia's MET in collaboration with the IIED designed a survey to assess forest resource utilization, through the development of asset and flow accounts (Barnes *et al.*, 2005).

The survey focuses on the semi-arid woodlands in the north-central regions (NCR). While only comprising 4 per cent of Namibia's land area, it is densely populated, supporting half of the country's population of around two million. Low-value rainfed crop production and livestock grazing along with forest use dominate the local, infrastructure-poor economy. Forest cover has declined in recent decades, especially in the densely settled central area of the NCR (see Erkkilä, 2001).

2.2. Surveys and data collection

The datasets were established in 2004. Household and focus group surveys were conducted to obtain data on the use of forest resources (specifically fuelwood, poles, and non-timber forest products (NTFPs)) among rural residents. The household questionnaire was aimed at obtaining quantitative information on volumes of forest products harvested, consumed, and sold, along with prices and harvesting costs.[5]

A stratified sample of 182 households from 19 villages in the Ohangwena, Omusati, Oshana, and Oshikoto sub-regions of NCR was selected. It was designed to cover residents in all of the biomes[6] present in the sub-regions. Household sampling within biomes was randomized on the basis of forest dependence for livelihoods (see MacGregor *et al.*, 2007). A comparison with NCR Census data from 2001 showed that household characteristics are, in

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[3] Up to 60 per cent of African fuelwood supply originates from non-forest areas (FAO, 2000).

[4] 2006 figure (source: www.cia.gov). Exchange rate used is US$1.00: N$6.30.

[5] Following two pilot surveys, six trained enumerators were deployed to interview household heads. A complementary sample of 25 forest product traders in the NCR was interviewed for information on forest products.

[6] The political regions are not differentiated according to ecology or biome, although the latter is more informative with respect to forest resource availability. The predominant biomes include western Kalahari, mopane shrubland, and mopane woodland. The physical data were collected according to political region alone, which typically incorporates estimates across different biomes.

general, representative of the entire population of the NCR. Furthermore, the NCR shares a number of characteristics (climate, flora, fauna, etc.) with other regions in northern Namibia. Thus, findings in this paper have policy implications beyond the NCR.

2.3. Descriptive statistics and Namibian resource accounts

Rural life in the NCR is largely based on subsistence, with 83 per cent of respondents classifying themselves either as subsistence farmers or unemployed. Compared to the national average, average incomes are low at around N$2,000, derived mostly from paid employment, local informal economic activity, and pensions. Access to a car is limited to less than 10 per cent of households, distributed evenly among political and ecological regions. At 7.5 people, average household sizes are large.

The NCR account for 10 per cent of Namibia's forest area, 29 per cent of forest biomass, and 27 per cent of physically suitable yield for fuelwood and poles (Nhuleipo *et al.*, 2005). The area also accounts for an estimated half of all Namibia's fuelwood demand and two-thirds of that for poles. Excluding the use of forests for grazing, Namibia's standing forests had a total asset value of almost N$600 million in 2004, with fuelwood alone accounting for over half of this estimate (Barnes *et al.*, 2005). Poles and fuelwood in the NCR account for around a third of the total asset value for the whole country. By contrast, Namibia's official forest sector contributed N$430 million to GDP in 2004, or 1.1 per cent of total GDP.

There is a high, local dependence on forest resources for cooking, heating, and building materials. On average, a household uses almost 12,000 kg of wood for energy and shelter annually, split between fuelwood and poles. The average per capita consumption of fuelwood is 913 kg, ranging from 144 kg in Oshana to 1,202 kg in Ohangwena. With annual harvests in fuelwood and poles exceeding the physically suitable annual yield, forests appear to be over-harvested in Oshana (see Nhuleipo *et al.*, 2005; MacGregor *et al.*, 2007). The other sub-regions are characterized by relative forest resource abundance rather than scarcity with current rates of use below sustainable yields. Over half of the sample is unaware of official restrictions about the utilization of public forest resources.

There is seasonal variation in fuelwood collection with stockpiling occurring between September and December. This is to ensure enough fuelwood in the household during the rainy season (see Nhuleipo *et al.*, 2005). Although data were not collected, field observations revealed that much fuelwood was gathered by women and children,[7] with collection linked to other activities, particularly livestock grazing.

Limited but active local markets exist for fuelwood and for other forest products such as NTFPs, as is typical for rural subsistence households (Hyde and Köhlin, 2000). There are 30 fuelwood-purchasing households, comprising 16 per cent of the sample. Of these, 22 buyers collect fuelwood as well. Fuelwood is typically bought from traders at open markets in the

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[7] Earlier studies, e.g. Williams (1983), have shown that fuelwood collection in Africa is dominated by women and children, while more recent ones have found that both men and women collect, e.g. Mekonnen (1998).

local town or by the side of the road. Purchased and collected fuelwood are sourced from similar areas. For the sample as a whole, fuelwood purchases account for 9 per cent of total annual consumption, and 39 per cent of annual consumption for the buying sub-sample. Only three households in the sample sell fuelwood, one of which also buys fuelwood. Thus, buyers easily outnumber sellers in the Namibian household sample.

In addition to fuelwood and poles, the main forest resources used by households are NTFPs, e.g. for food, medicine, and cosmetics. Almost 80 per cent of sampled households received some income from NTFPs, while an average of 19 per cent of declared household incomes across the sample were derived from NTFP sales (MacGregor *et al.*, 2007). Forest resources are also used for grazing and shelter of livestock. There are substantial tracts of open-access grazing land throughout the NCR, and ownership of livestock (cattle, goats, donkeys) is widespread. Respondents do not purchase fodder for their livestock.

3. Household model

The model captures a rural subsistence household engaged in agricultural production, off-farm work, and energy collection. Namibian households are located in an environment characterized by market failures for some of their inputs, e.g. to agricultural production, and products. A market may fail for a particular household when it faces 'wide' price margins between the low price at which it could sell a commodity or factor and the high price at which it could buy that product or factor (Sadoulet and de Janvry, 1995).[8] Faced with such a margin, the household may choose self-sufficiency in the good or factor if its shadow price falls inside the margin. Given the relatively small numbers of buyers and (in particular) sellers, the Namibian dataset provides limited evidence for a fuelwood price band: average sales and purchase prices are N$0.33 and N$0.41 per kg, respectively.[9]

As most rural domestic fuels are not traded but produced and consumed by the household itself, the model used is non-separable (or non-recursive).[10] When markets fail, there are direct interrelations between production and consumption decisions. In the context of energy collection, this implies that household resource allocation (including energy supply, energy demand, and farm and off-farm labour supply) is decided simultaneously. Each household determines energy production and consumption by maximizing its utility subject to a shadow price of energy which is unobserved and unknown except to the household itself. Such a model was originally developed by Amacher *et al.* (1999)

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[8] The size of the price band may rise due to one or a combination of transactions costs, shallow local markets, price risks, and risk aversion (Sadoulet and de Janvry, 1995).

[9] To place these figures in perspective, if households were to purchase all their fuelwood from the market, an average fuelwood consumption of 5,572 kg per year (from table 1) would imply annual expenditure of over N$2,200, easily in excess of average annual incomes.

[10] The full household model was originally developed by Barnum and Squire (1979), and further elaborated in Singh *et al.* (1986).

and Heltberg *et al*. (2000), focusing on the substitution of forest and non-forest fuels in Nepal and India, respectively. Closely following Heltberg *et al*. (2000), our model focuses on the choice of energy sources for heating and cooking, among fuelwood gathered from the forest, producing energy using cow dung and fuelwood purchases. The hypothesis to be tested is that fuelwood, dung, and marketed energy sources are substitutes in domestic energy consumption. First, the household maximizes utility defined as

$$\underset{c_{FW},c_M,q_{FW},q_{AG},q_D,l_{FW},l_{AG},l_{OFF}}{Max U} = U(c_E, c_M, c_L; z^{HC}), \tag{1}$$

where c_E denotes consumption of household goods and services such as cooked food and heating that require energy inputs; c_M are other consumption goods and services; and c_L is leisure for all working household members. No distinction is made between time allocation for male and female household members due to a lack of data. z^{HC} is a vector of household characteristics relating to consumption such as wealth and household size.

In the Namibian context, household goods and services, including cooking and heating, are mainly produced with energy inputs from fuelwood and dung

$$c_E = \Gamma(c_{FW}, c_D). \tag{2}$$

Consumption of fuelwood collected from *de facto* open access forest areas,[11] as undertaken by 86 per cent of sampled households, is denoted c_{FW}. Consumption of dung, by 13 per cent of sampled households, is denoted c_D. No stove technology or similar is used by any of the sampled households.

As described in the previous section, there are 30 households, comprising 16 per cent of the sample that bought fuelwood during the study period. Only three households sold fuelwood. The net marketed quantity of fuelwood is thus $q_{FW} - c_{FW}$, where q_{FW} denotes household fuelwood production. If no fuelwood is bought or sold by the household, this quantity is equal to zero, i.e. supply is equal to consumption. To simplify the model and the empirical analysis in the following section, we focus on fuelwood buyers and non-buyers, hence excluding sellers. The net, non-negative amount of fuelwood used in the household can be written as

$$c_{FW} - q_{FW} \geq 0. \tag{3}$$

Fuelwood production is assumed to be a concave function of household labour time spent collecting fuelwood, l_{FW}, and household fixed factors of production (e.g. harvesting equipment such as hand-held parangs), a_{FW}

$$q_{FW} = g_{FW}(l_{FW}, a_{FW}; z^V), \tag{4}$$

where z^V is a vector of exogenous characteristics describing forest stock and access conditions. These include population density, management institutions, and distance from the household to the forest.

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[11] Namibian households do not tend to have private forest resources that other households cannot access.

Households produce agricultural goods using the following production function

$$q_{AG} = g_{AG}(l_{AG}, d_{AG}; z^K), \tag{5}$$

where l_{AG} is household farm labour, d_{AG} denotes the use of animal dung as an agricultural input, and z^K is a vector of household agricultural endowments such as land and livestock. Labour was not hired in by any of the sampled households. As in Heltberg *et al.* (2000), the total amount of dung available is modelled as a fixed proportion of agricultural output αq_{AG}. To capture the trade-off in using dung as a farm input or as a source of energy, dung energy supply is given as net of dung not used as inputs

$$q_D = \alpha q_{AG} - d_{AG}, \tag{6}$$

where q_D denotes the amount of dung collected by the household from cattle left to graze in fields and forest. Dung is not traded, i.e. consumption of dung equals production, $q_D = c_D$. The household budget constraint is given by the income from agricultural production, off-farm employment, and other sources such as savings

$$p_{AG} q_{AG} + w l_{OFF} + e = p_M c_M + p_{FW}(c_{FW} - q_{FW}), \tag{7}$$

where p_{FW}, p_{AG}, and p_M refer to the exogenous, market prices of fuelwood, agricultural goods, and other goods, respectively; w is the exogenous wage rate; l_{OFF} is household labour time in off-farm work; and e is other household income.

Households have a labour endowment, T, which is allocated over fuelwood collection and on- and off-farm employment. Thus, total household leisure, c_L, is

$$c_L = T - l_{AG} - l_{OFF} - l_{FW}. \tag{8}$$

Additional to (3), the following non-negative constraints apply to the model

$$\begin{aligned} &q_i \geq 0; \quad c_j \geq 0; \quad l_K \geq 0 \\ &i = FW, AG, D; \\ &j = L, FW, D, M, E; \\ &k = FW, AG, OFF \end{aligned} \tag{9}$$

By inserting (2)–(8) into (1), the Lagrangian for an internal solution to the problem can be formulated

$$\begin{aligned} \ell = {} & U\left[c_M, \Gamma\left(c_{FW}, q_D\right), T - l_{AG} - l_{OFF} - l_{FW}; z^c\right] \\ & - \lambda\left[p_M c_M + p_{FW}(c_{FW} - q_{FW}) - p_{AG} q_{AG} - w l_{OFF} - e\right] \\ & - \eta\left[q_{AG} - g_{AG}\left(l_{AG}, \alpha q_{AG} - q_D; z^K\right)\right] \\ & - \psi\left[q_{FW} - g_{FW}\left(l_{FW}, a_{FW}; z^V\right)\right] - \mu\left[q_{FW} - c_{FW}\right] \end{aligned}$$

The first-order conditions for this problem are

$$\frac{\partial \ell}{\partial c_{FW}} = \frac{\partial U}{\partial \Gamma} \frac{\partial \Gamma}{\partial c_{FW}} - \lambda p_{FW} - \mu = 0$$

$$\begin{aligned}
\frac{\partial \ell}{\partial c_M} &= \frac{\partial U}{\partial c_M} - \lambda p_M = 0\\
\frac{\partial \ell}{\partial q_{FW}} &= \lambda p_{FW} - \psi + \mu = 0\\
\frac{\partial \ell}{\partial q_{AG}} &= \lambda p_{AG} + \eta\left[\alpha \frac{\partial g_{AG}}{\partial d_{AG}} - 1\right] = 0\\
\frac{\partial \ell}{\partial q_D} &= \frac{\partial U}{\partial \Gamma}\frac{\partial \Gamma}{\partial q_D} - \eta \frac{\partial g_{AG}}{\partial d_{AG}} = 0\\
\frac{\partial \ell}{\partial l_{FW}} &= \psi \frac{\partial g_{FW}}{\partial l_{FW}} - \frac{\partial U}{\partial c_L} = 0\\
\frac{\partial \ell}{\partial l_{AG}} &= \eta \frac{\partial g_{AG}}{\partial l_{AG}} - \frac{\partial U}{\partial c_L} = 0\\
\frac{\partial \ell}{\partial l_{OFF}} &= \lambda w - \frac{\partial U}{\partial c_L} = 0
\end{aligned}$$

$$\mu > 0, \text{if } c_{FW} - q_{FW} > 0; \mu(c_{FW} - q_{FW}) = 0 \text{ otherwise, where } q_{FW} = c_{FW}. \tag{10}$$

The conditions in (10) can be rearranged to give

$$\frac{\partial U}{\partial c_L} = \eta \frac{\partial g_{AG}}{\partial l_{AG}} = \psi \frac{\partial g_{FW}}{\partial l_{FW}} = \lambda w. \tag{11}$$

Equation (11) shows how the household allocates its time among leisure, fuelwood collection, and agricultural activities. More precisely, households collect fuelwood until the marginal utility of leisure, i.e. the opportunity cost of household labour, is equal to the marginal product of household labour in agriculture, which in turn is equal to the marginal product of household labour in fuelwood collection. It is also equal to the off-farm labour wage.

While only limited fuelwood markets exist, it can be seen from the first and third conditions in (10) that the marginal utility of fuelwood consumption for all households is equal to the shadow cost of collecting it, ψ. For the majority of sampled households, the reservation price of fuelwood is lower than the purchase price and higher than its sale price implying that they prefer to consume whatever they collect, i.e. are self-sufficient.[12] For buyers, the reservation price exceeds the market buying price, N$0.41 per kg, at the upper-end of the price band. Thus, the market price determines fuelwood production and consumption levels for fuelwood buyers.

Dung is used for energy production and as an input to agriculture. From the fifth condition in (10), dung is used as a source of energy until the marginal utility of energy is equal to the marginal product of dung as an

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[12] For fuelwood sellers, the market selling price can be said to exceed their reservation price for fuelwood.

agricultural input. Thus, dung use is determined by the opportunity cost of dung as an input to agriculture.

In summary, fuelwood collection is determined by the households' opportunity costs of time, which are mainly determined by agricultural activities. Dung use is determined by the opportunity costs of using dung as an input to agriculture. The opportunity costs of household time are driven by the wage. An increase in the wage draws labour away from agriculture, and also from fuelwood collection.[13]

4. Empirical application

To test for the determinants of energy sources among rural households in Namibia, the model presented in section 3 is applied empirically to the dataset presented in section 2. Missing markets for fuelwood and labour across the sample and the non-separable property of the model imply that household fuelwood demand and supply decisions have to be considered together. From the first-order conditions in (10), four reduced-form equations are derived, showing amount of fuelwood collected, amount of time spent collecting, amount of dung produced, and amount of fuelwood consumed as functions of all the exogenous variables[14]

$$\left.\begin{matrix} q_{FW} \\ l_{FW} \\ q_D \\ c_{FW} \end{matrix}\right\} = f(p_{FW}, p_{AG}, p_M, w, z^H, z^V, z^C, T) \tag{12}$$

These equations are used to investigate the household demand for energy in Namibia.

The household sample consists of 29 buyers, two sellers, one buyer and seller, and 150 households that neither bought nor sold fuelwood. The presence of numerous sub-groups complicates the empirical analysis, although the very small sizes of the seller and buyer/seller sub-samples preclude these from further meaningful consideration. Divided between buyers and non-buyers, the sample is reduced to 179 households; the buyer sub-sample can be further divided into 22 buyer-collectors and seven buyers. Following Acharya and Barbier's (2002) study of groundwater valuation in Nigeria, fuelwood demand in Namibia is estimated by considering first, the demand for collected fuelwood using 'collect-only' and 'collect-and-purchase' households only, followed by the demand for purchased fuelwood using 'purchase-only' and 'collect-and-purchase' households.

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[13] Where there may be direct links between fuelwood collection and deforestation, an increase in off-farm wages may reduce pressures on forests (see Kaimowitz and Angelsen (1998) for a review).

[14] An inability to separate consumption and production decisions in the household means that there are no restrictions on functional form and parameters, at least when considering the reduced form in (12). Consequently, price, wage, income, and resource variables must all remain as explanatory variables in all equations, i.e. the model is identically specified for each equation (Amacher *et al.*, 1996).

As noted in the previous section, purchase-only (PO) households face fuelwood market prices, while collect-only (CO) households are influenced by unobservable shadow prices. Collect-and-purchase (CAP) households face both market and shadow prices for fuelwood, which may be different for some households (see Amacher *et al.*, 1996). The presence of different price regimes among households cannot be accommodated by dividing the sample and conducting separate ordinary least squares (OLS) regressions. Since households are distributed non-randomly, this would lead to inconsistent parameter estimates and selectivity bias. The method used to address this problem and estimate the parameters of the model is Heckman's (1976, 1979) two-step estimator, in which a prediction from the first model is used as a covariate in a second model.[15] For estimating collected-fuelwood demand, the binary indicator variable is whether or not households buy fuelwood; for purchased-fuelwood demand, the binary variable is whether or not households collect fuelwood. Chow tests of structural change are applied to examine whether or not there are any behavioural differences between the sub-groups in the sample.

The independent variables used for estimation are listed and summarized in table 1, along with their summary statistics. Given the original focus of the fieldwork on constructing forest resource accounts, these data are limited in their application to this analysis, e.g. there is no variable that can usefully proxy for household labour endowment, T.

Cow dung is not traded and, hence, its price is not included among the independent variables. Since dung is used as an energy input, its relative scarcity is assessed through head of cattle owned. This is expected to have a positive impact on dung consumption because households with larger herds have easy access to dung. Cattle owned also proxies for household capital, z^K, since these tend to be the household's most valuable form of capital.[16] Moreover, households with more cattle tend to have other forms of capital, which were not captured in the survey. For a given labour input, greater capital may have a positive impact on agricultural production and household incomes. Income and cattle owned are not collinear. In turn, this may induce a greater consumption of leisure in addition to goods and services requiring energy inputs. The expected effect on fuelwood consumption is positive, while those for fuelwood collection and labour input to fuelwood collection are unclear.

Regarding other household characteristics, z^{HC}, household size is expected to influence fuelwood collection positively, both because of increased energy demand (e.g. for cooking) and because of increased labour supply. The expected impact of household size on dung consumption is unclear because more household labour means increased demand for energy, but also greater scope for substituting fuelwood, which is relatively

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[15] See also Murphy and Topel (1985). As recommended by Puhani (2000), exploratory work is undertaken to reduce collinearity problems among the independent variables in order to justify the use of Heckman's two-step estimator.

[16] A separate variable for total numbers of livestock owned is not possible due to collinearity with head of cattle. Since cattle are more valuable compared to other livestock, these alone act as a reasonable proxy for household capital in our sample.

Table 1. *Independent and dependent variables*

Variable	*Definition*	*Mean values*	*St. dev.*	*Range*
	Endogenous (dependent) variables			
Amount of fuelwood collected	Fuelwood collected by the household in one year in kg	5071	4190	0–21900
Amount of fuelwood consumed	Fuelwood consumed by the household in one year in kg	5572	4989	0–30000
Labour input to fuelwood collection	Total collection time for fuelwood in hours per year per household	195	260	0–460
Amount of dung consumed	Dung consumed by the household in one year in kg	901	2981	0–18250
	Exogenous (independent) variables			
Forest stock	Availability of forest biomass; population per cubic metre of forest biomass in each political region	0.036	0.061	0.0036–0.21
Cattle	Number of cows owned by the household	9.43	14.5	0–80
Income	Exogenous household income in N$ per household	1,877	2,981	0–13,500
Cutting regulation	Awareness of state restrictions on harvesting of public forest resources, where 1 codes for awareness	–	–	–
Household size	Number of people living in the immediate household	7.61	4.85	0–48
Education	Number of years household head in state education system	6.34	3.76	0–14
Fuelwood market price	Market price in N$ per kg of fuelwood purchased	0.43	0.23	0.06–0.83
Fuelwood collection time	Collection time in hours per kg of firewood collected	0.072	0.094	0.001–0.89
Gender of household head	Gender of household head where 1 codes for male	–	–	–

Source: Ministry of Environment and Tourism (MET), Namibia.

labour intensive, for dung. There are data on exogenous market incomes for almost all households. Wealthier households may collect less of their own fuelwood and rely more on market purchases with an indeterminate overall effect on fuelwood consumption.

Collection time (per kg of fuelwood collected) captures the shadow price of gathering fuelwood. Potential endogeneity is tested by undertaking the Durbin–Wu–Hausman test.[17] With the exceptions of amounts of fuelwood collected and consumed, the coefficient of the residuals for collection time is found to be insignificant (including at the 0.10 level) when considering each of the dependent variables. For estimating fuelwood collection and consumption, a three-stage model is adapted from Mroz (1987) to control for sample selection bias and endogeneity. Stages one and three are similar to the usual two-step estimator, while stage two is similar to the first step of a two-stage least squares (2SLS) estimation. An instrumental variable (IV) in the form of gender of household head is fitted to collection time in stage two.[18] Increasing shadow prices are expected to have a negative effect on fuelwood collection. Labour allocated to collection is also expected to rise with increasing shadow price. The estimation of demand for collected fuelwood combines the CO and CAP households, which totals 172 households, i.e. excluding PO households.

For CAP households, the decision to buy fuelwood occurs when its market price, p_{FW}, is either smaller than or equal to its shadow price. Rising shadow prices may be expected to increase fuelwood purchases, although a decline in collection means that the overall effect on consumption is unclear. Given missing markets, market prices are unlikely to be completely exogenous. Potential endogeneity is again tested using the Durbin–Wu–Hausman test, with market prices not found to be endogenous. Holding all else equal, we expect rising market prices to increase the amount collected. PO and CAP households are combined to estimate the demand for purchased fuelwood. Since this sub-sample only totals 29 households, its small size implies that we treat the results with caution.

Cross-price elasticities of demand for fuelwood and dung are used to assess the extent to which households substitute among energy sources. Substitution between dung and fuelwood can be evaluated through the impact of price on dung consumption and through the effect cattle herd size has on dung collection. Increasing prices are expected to have a positive impact on use of dung. A number of household dung collectors neither collect nor buy fuelwood. Other households only buy but do not collect fuelwood. Missing price observations for these 28 non-fuelwood collecting

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[17] First, collection time is regressed on the other independent variables selected in this section and then the residuals of collection time are included as independent variables with the other variables in an augmented regression for each equation.

[18] Stage one is a selection equation (probit) while stage two is a reduced-form regression in which the endogenous variable, collection time, is estimated using the inverse Mills ratio (IMR) from stage one, the IV (gender of household head), and a number of control variables. In stage three, the structural equation is estimated using the predicted value of collection time (from stage two), the IMR from stage one along with a set of control variables.

households are proxied by upper-bound collection time data collected for other households sampled in their villages and respective ecological regions. In light of potential biases in the regression results, a sensitivity analysis is undertaken in the next section using the lower-bound collection time estimates.

Data for agricultural output prices, p_{AG}, and those for other goods, p_M, were not collected. However, fieldwork observations confirm the assumption that these vary relatively little across households. Also, data for off-farm wage rates, w, are unavailable. Instead, a continuous variable measuring the number of years the household head had spent in education is included to account for unobserved labour market opportunities. Greater labour market opportunities are expected to effect less input to fuelwood collection, less fuelwood and dung collection, and more fuelwood purchases. Another proxy for labour market opportunities is age of household head; a relatively young household head may have the skills, strength, and ambition to realize an off-farm labour opportunity compared to an older one. However, age is collinear with a number of other variables thus excluding it from the model.

Collected fuelwood can have high opportunity costs, which varies according to the density, distance, and accessibility of forest resources (z^V). Forest stock availability is measured as a ratio of population per cubic metre of forest biomass in each political region. These stocks are assumed to be contained within public forests. With higher population relative to forest stock, it is expected that more households will substitute fuelwood for dung. Access to forest for fuelwood could be given by distance from the household, although this is collinear with collection time. While improved access to forest resources or to the market could be measured through access to motorized transport, the data are limited to private ownership and no information is available on access to public forms of transport. Awareness of state restrictions on harvesting open access forest resources is included as a dummy variable. Increased awareness is expected to lead to less fuelwood collection, more dung use, and more fuelwood purchases.

5. Empirical results and discussion

Chow F-test results, shown in tables 2 and 3, demonstrate that the pooling of CAB and CO households in a single sample is not rejected by the data, i.e. there appears to be few behavioural differences between buyers and non-buyers. Due to small sample size, the validity of data pooling is not tested for PO and CAB households. All regressions are estimated using the Heckman two-step estimator in which a predictor from the first, probit model is used as a covariate in a second, linear regression model. For fuelwood collection and consumption, an extra stage is introduced in order to control for endogenous shadow prices. In the probit model, variable values are only recognized when the household is identified as a fuelwood buyer (collector) in estimating the demand for fuelwood collected (purchased). In the final stage, the predictors are regressed on buyer-dependent (collector-dependent) variable values. Results for collected- and purchased-fuelwood demand are reported separately for each equation, i.e. using shadow and

Table 2. *Final stage model estimates (MLE) – amount of fuelwood collected and consumed*

	Amount of fuelwood collected						*Amount of fuelwood consumed*					
Variable		*Market price*			*Shadow price (IV)*			*Market price*			*Shadow price (IV)*	
Constant		5741 (8606)			7622 (2210)***			6974 (22413)			7733 (2267)***	
Forest stock	–	−1071 (136506)	−0.0006	–	−20871 (8660)**	−0.14	–	−19708 (436728)	−0.09	–	−21012 (8766)**	−0.13
Cattle	+/−	−79.4 (385)	−0.12	+/−	−45.0 (28.5)*	−0.08	+/−	83.4 (880)	0.08	+/−	−50.0 (28.8)*	−0.08
Income	–	−0.52 (7.75)	−0.15	–	−0.034 (0.67)	−0.01	+/−	2.32 (25.2)	0.41	+/−	0.18 (0.69)	0.06
(Income)^2		−0.000063 (0.0030)			0.00020 (0.00019)			−0.00081 (0.011)			0.00063 (0.00019)	
(Income)^3		0.69D-09 (0.23D-06)			−0.15D-08 (0.12D-07)			0.64D-07 (0.86D-06)			0.36D-08 (0.12D-07)	
Cutting regulation	–	499 (4356)		–	−474 (754)		+/−	−2103 (10837)		+/−	−665 (772)	
Household size	+	195 (362)	0.37	+	163 (73.9)**	0.23	+	340 (807)	0.41	+	203 (58.5)***	0.28
Education	–	−230 (565)	−0.26	–	79.6 (97.7)	0.09	+/−	143 (1492)	0.10	+/−	70.3 (99.3)	0.08
Fuelwood market price	+	545 (21561)	0.04				+/−	−8463 (19870)	−0.43			
Fuelwood collection time				–	−38779 (25814)*	−0.05				+/−	−41770 (26834)*	−0.05
Sample size (degs of freedom)		29 (18)			172 (161)			29 (18)			172 (161)	
Chow F-test		–			0.55			–			0.47	
R^2		0.67			0.23			0.54			0.26	

Notes: For each regression equation, the first column gives the expected sign, the second gives the coefficient and standard error, and the third gives the elasticity (evaluated at the mean). *significant at the 0.10 level; **significant at the 0.05 level; ***significant at the 0.01 level.
Source: Ministry of Environment and Tourism (MET), Namibia.

Table 3. *Final stage model estimates (MLE) – amount of dung consumed and labour input to fuelwood collection*

	Amount of dung consumed						*Labour input to fuelwood collection*					
Variable		*Market price*			*Shadow price*			*Market price*			*Shadow price*	
Constant		3599 (3735)			−683 (819)			−6974 (22413)			149 (79.9)*	
Forest stock	+	−571 (81274)	−0.001	+	19071 (3583)***	0.82	–	−19708 (436728)	−0.09	–	−1363 (391)***	−0.23
Cattle	+	44.1 (200)	0.23	+	30.8 (8.48)***	0.34	+/−	83.4 (880)	0.08	+/−	1.03 (1.16)	0.05
Income	–	−5.61 (3.22)*	−5.35	–	−0.63 (0.63)	−1.43	–	2.32 (25.2)	0.41	–	−0.035 (0.047)	−0.32
(Income)^2		0.0021 (0.0013)			0.00085 (0.00016)			−0.00081 (0.011)			0.00010 (0.00011)	
(Income)^3		−0.14 (0.13D-06)			−0.34D-08 (0.10D-07)			0.64D-07 (0.86D-06)			0.62D-09 (0.62D−09)	
Cutting regulation	+	1646 (2389)		+	−508 (708)		–	−2103 (10837)		–	7.61 (46.1)	
Household size	+/−	16.3 (16.3)	0.11	+/−	75.5 (45.5)*	0.71	+	340 (807)	0.41	+	5.45 (5.14)	0.20
Education	–	−40.1 (491)	−0.15	–	91.5 (80.9)	0.72	–	143 (1492)	0.10	–	−4.01 (6.81)	−0.12
Fuelwood market price	+	−4078 (9011)	−1.10				+/−	−8463 (19870)	−0.43			
Fuelwood collection time				+	2606 (3999)	0.02				+	1262 (130)***	0.04
Sample size (degs of freedom)		29 (18)			172 (161)			29 (18)			172 (161)	
Chow F-test		–			1.25			–			1.33	
R^2		0.67			0.27			0.54			0.26	

Notes: For each regression equation, the first column gives the expected sign, the second gives the coefficient and standard error, and the third gives the elasticity (evaluated at the mean). *significant at the 0.10 level; **significant at the 0.05 level; ***significant at the 0.01 level.
Source: Ministry of Environment and Tourism (MET), Namibia.

market prices, respectively.[19] Despite its consistency, the relative inefficiency of the Heckman estimator suggests using the maximum likelihood estimate (MLE) of the same model (see Puhani, 2000).

The final stage MLE results from the selection model regressions of fuelwood collection and consumption, labour allocation to collection, and dung consumption are presented in tables 2 and 3. Due to the presence of heteroscedasticity in the income variable, a third-degree polynomial in household income variable is included in all four equations. The model generally conforms to prior expectations. With collinearity problems minimized, the MLE gives interesting results that are robust to minor changes in specification.

The prediction success rate is high at around 90 per cent for the probit equation in all equations. Although the probit results are not shown in the tables, relatively insignificant effects are recorded for all variables on the probability of being a fuelwood purchaser (or collector).

As shown in tables 2 and 3, respectively, fuelwood collection time has a negative effect on the amount of fuelwood collected (with instrumentation) and a positive effect on labour input to fuelwood collection. Both effects are significant. As forest resources become increasingly scarce, CO and CAP households react by reducing the amount collected. A 1 per cent increase in time to collect one kg of fuelwood results in a 0.05 per cent decline in the amount of fuelwood collected, thus revealing price inelasticity. A similar effect was found for consumption, which suggests that households are not responding to economic scarcity by purchasing more fuelwood from the market. This estimate is lower than those observed by Amacher *et al.* (1993) and Heltberg *et al.* (2000).[20] Mekonnen (1999), using demand shadow price rather than collection time, obtained a less inelastic result in the more arid uplands of Ethiopia. A 1 per cent increase in collection time also leads to 0.04 per cent increase in labour input to fuelwood collection, a result that is consistent with those found, for example, by Kumar and Hotchkiss (1988) and Cooke (1998a,b). Thus, households respond to economic scarcity, as measured by collection time, by reducing energy consumption just slightly more than by increasing labour input to collection and, hence, household expenditures.[21] In general, CO and CAP households appear to be less responsive to changes in shadow prices than to changes in other variables such as household size or the availability of forest stock.

On the basis of a limited sample of PO and CAP households, i.e. with relatively few degrees of freedom, increasing market prices seems to have positive though insignificant impacts on the amount of fuelwood collected (table 2), labour input to collection and dung collection (table 3). As market

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[19] Since CAP households are included in both demand estimates, this could lead to error correlation across equations. Seemingly, unrelated regression estimation (SUR) techniques could be applied to resolve this problem (see Greene, 1993).

[20] Our results are also consistent with other Asian estimates, e.g. Lind-Rahr (2003) and Pattanayak *et al.* (2004).

[21] Without instrumentation, households respond to economic scarcity by increasing labour input to fuelwood collection more than by reducing energy consumption. However, the difference is also negligible. Demand remains comparably inelastic.

prices rise, however, households seem to respond by reducing overall fuelwood consumption more than by increasing fuelwood collection. These directions of effect for market prices on fuelwood demand are consistent with those found by Acharya and Barbier (2002) in their study of water demand in Nigeria. Similar to households in Nepal (Amacher *et al.*, 1996), fuelwood market participants may be more price responsive than non-participants.

With respect to dung consumption, in table 3 the effect of collection time is positive but insignificant. This suggests that households do not respond to scarcity by switching directly from fuelwood to dung collection. These results are consistent with those obtained by Kumar and Hotchkiss (1988), Amacher *et al.* (1993), and Heltberg *et al.* (2000). Our elasticity estimate, 0.02, is smaller than that of Heltberg *et al.* (2000), a result they also found to be insignificant.[22]

Cattle ownership is found to significantly increase dung collection for CO and CAP households. As expected, owning cows leads to the increased availability of dung both for energy and as an agricultural input. Evidence for dung being used as an energy source can be seen with the negative and significant impact of cattle ownership both on fuelwood collection and consumption in table 2. Cattle ownership appears to be a better proxy of dung price than of household capital at least when considering the CO and CAP households. This result, while very inelastic, seems to imply that dung is used to a limited extent as an energy substitute for fuelwood instead of as an input to agriculture. Data on agricultural inputs would be required to substantiate this, however. Cattle ownership has a positive albeit insignificant impact on labour input to fuelwood collection. Households with larger herds may spend more time in grazing areas, which often doubles-up as time for collecting fuelwood as well.

Availability of forest stock, measured as the ratio of population to forest biomass, is found to have a positive and significant effect on dung collection, while having a negative and significant effect on labour input to fuelwood collection (for CO and CAP households). In other words, the greater (smaller) the number of people relative to available biomass, the more (less) dung that is collected and the smaller (greater) the labour input to fuelwood collection (see table 3). Thus, a 1 per cent increase in the ratio of people to forest stock leads to a 0.82 per cent increase in dung collected (equal to approximately 80 kg) and a 0.23 per cent decline in labour input to fuelwood collection (equal to 40 hours). These estimates, while having similar signs, are inelastic compared to those observed in Heltberg *et al.* (2000). Moreover, Mekonnen (1999) finds that Ethiopian households do not use less dung when forest biomass is more available due to complementarity between dung and fuelwood for cooking particular local dishes. Similar to Heltberg *et al.* (2000), the effects of forest stock availability on fuelwood collection are also significant for CO and CAP households, i.e. the greater the ratio of people to available biomass, the less fuelwood that is collected.

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[22] Note that this result is for the consumption of all private fuels (crop residues, dung, etc.), and not just for dung alone.

Overall consumption also seems to decline with declining availability of forest stock.

Taken together, these results provide limited evidence for substitution between dung and fuelwood. With increasing scarcity, poor rural households usually have relatively few alternatives available to them (Cooke *et al.*, 2008). Rearing cattle may require substantial investment, suitable grazing areas, as well as specialized knowledge. For poorer households residing in densely populated areas with relatively little pastoral knowledge, substituting between fuelwood and dung may not be a feasible option. Households in arid areas such as Oshana, where a pastoralist culture is long established and where forest stocks have long been low, increasing dung collection would be a rational response to physical scarcity. Note, however, that cattle grazing also leads to the degradation of forest resources and, hence, physical scarcity, which in turn may affect the household response to scarcity.

Size of household has a positive and significant impact both on fuelwood collection and consumption. A weaker though still positive effect is observed for dung collection when considering CO and CAP households. These results show that larger households have higher energy demands. Household size has a positive though insignificant effect on labour input to fuelwood collection, in contrast to Heltberg *et al.* (2000) who found a significant result.

The other independent variables listed in tables 2 and 3 generally have weaker effects on the dependent variables. In particular, household incomes and years of education (a proxy for off-farm labour opportunities) appear to have little impact on household behaviour. The exception is that increasing income in PO and CAP households has a negative and highly elastic impact on dung consumption. The directions of effect are as anticipated for dung collection and labour input to fuelwood collection. Small negative income effects on fuelwood production should be contrasted with positive effects on overall consumption, which suggests that fuelwood purchases may be making up the difference as incomes rise. Mekonnen (1999) found a similar albeit significant result for income effects on consumption in Ethiopia. Awareness of state restrictions on the utilization of forest resources also has little effect on fuelwood consumption or collection, although not all the signs on the coefficients are as expected. One explanation may be that most households know that they can harvest fuelwood with impunity in areas where the government's capacity to enforce its own rules may be very weak.

In section 4, missing shadow price observations for the 28 non-fuelwood collecting households in the sample were approximated to upper-bound collection time data collected for other households residing in the same villages and ecological regions.[23] A sensitivity analysis is undertaken to

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[23] Note that there are wide disparities between the upper- and lower-price bounds even among households in the same village. Forest resources in villages in Oshana tend to be particularly scarce, compared to the sample as a whole. The justification for using the upper rather than lower estimates is that the lower ones are almost all derived from the relatively few households that have access to a private vehicle and can travel long distances to find and gather fuelwood. As a result, collection

test the upper-bound assumption. Data for the lower-bound estimates are entered into the four equations. The results show that the independent variables remained consistent in their effects on the dependent variables. One exception is a weakening of the effect of collection time on fuelwood collection. This is perhaps to be expected given that use of lower-bound price estimates decreases the measure of economic scarcity.

6. Conclusions and policy implications

A household model for domestic energy supply and demand is estimated using primary data originally collected in the NCR of Namibia for the development of its forest resource accounts. As described in section 2, the population of the NCR relies on forests for its energy needs and shelter as well as providing shelter and grazing for livestock. Our findings for northern Namibia are also relevant for people residing on semi-arid, communal lands throughout southern Africa where fuelwood demand continues to rise (FAO, 2007).

Despite the limitations of the survey data, the results of the empirical analysis presented in section 5 broadly support the predictions made in sections 3 and 4. In line with previous studies, including those undertaken in South Asia, many of the key estimated elasticities are very low. As fuelwood is a basic necessity, perhaps only the poorest households should be expected to be particularly responsive to fuelwood (economic) scarcity (Hyde and Köhlin, 2000). We find that Namibian households respond to increasing economic scarcity by reducing fuelwood consumption just slightly more than by increasing labour input to collection, although the difference is negligible. The inelasticity of fuelwood demand, however, suggests limited scope for demand-side policy interventions (Cooke *et al.*, 2008).

The response to economic scarcity in our sample is underlined by the relative abundance of forest resources in three out of four sub-regions, as revealed by the resource accounts. Nevertheless, increasing ratios of people to biomass, i.e. decreasing availability of forest resources, in these areas negatively impacts on the amounts of fuelwood collected and consumed, and labour input to collection. Thus, rising populations may impact on fuelwood demand even in areas where current rates of extraction are far below physically suitable annual yields. Given relative forest abundance in many areas, policies to encourage population dispersal may improve forest stock availability for fuelwood-dependent households without necessarily leading to over-harvesting.

There is limited evidence for substitution between fuelwood and dung. The inelasticity of fuelwood demand suggests that there are few genuinely close substitutes available. Using cattle dung as an energy source instead of fuelwood only appears to be a serious option where cattle herding is already a way of life, which can be passed on from generation to generation, and where there is acute physical forest scarcity, i.e. in Oshana. Adoption of

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times for these households are among the lowest in the entire sample and, hence, are not representative of most households. It is for this reason that the fuelwood prices for non-collecting households have been approximated to the upper bound estimates.

cattle herding by households on a wider scale is likely to be very difficult given costs and a lack of grazing lands in densely populated areas.

Policy intervention could also focus on purchased fuelwood markets. Our analysis shows that making a distinction between collecting and purchasing households is important. Small sample size means that we should, however, interpret our results with caution. Should these hold in a larger sample of market participants, we may find that households are generally more price responsive than non-participating households. This in turn might give more leeway with regards to demand-side policy interventions. Improving market participation, for example, by reducing transaction costs or supporting prices and regulating local markets may enable better control of the local commons while improving welfare in households with higher opportunity costs.

Given the importance of the role of women and children in collecting fuelwood in many parts of Africa, one key weakness of our study is the lack of distinction among household members and how fuelwood collection is allocated. We would certainly expect some differences in opportunity cost of time among men, women, and children. A follow-up survey would benefit from making such a distinction, along with data collected on local resource management, market access, and household landholdings.

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Paper III

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Economic Efficiency and Incentives for Change within Namibia's Community Wildlife Use Initiatives

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Summary. — Five community wildlife conservation and utilization initiatives, or conservancies, on communal land in Namibia were appraised to determine economic and financial worth. Conservancies are economically efficient and able to contribute positively to national income and the development process. They also provide a channel for the capture of international donor grants (wildlife non-use values) as income, and generate attractive financial returns for communities. Donor grants are very important catalysts in promoting land use change in conservancies. Ability to generate income from tourism is important. Flexibility and adaptability in design are key factors, ensuring effective rural development and conservation. © 2002 Elsevier Science Ltd. All rights reserved.

Key words — Africa, Namibia, community, wildlife, economics, incentives

1. INTRODUCTION

In this paper, five community wildlife conservation and utilization initiatives, on communal land in Namibia, have been analyzed to determine their financial profitability, and their economic efficiency. The degree to which these community projects can contribute positively to the national income, and thereby to the economic development process, is central to the study. Also investigated was the degree to which the initiatives provide private returns to project investment, as well as to investments made by communities.

Namibia has adopted policy and legislation to allow community-based natural resource management (CBNRM) [1] on communal land. Much of the initial focus of CBNRM has been on wildlife, which is threatened with displacement by growing rural human populations and illegal use. The approach devolves rights over wildlife to local communities and aims to make wildlife conservation part of the rural development process. In this context, CBNRM initiatives must be financially attractive for the community, economically efficient for the

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country, and reasonably financially viable for donors and the government. Without these incentives, they will not be sustainable, and will not result in development or conservation.

(a) *The setting*

Namibia is a large country (830,000 km^2) straddling the Tropic of Capricorn on the west coast of southern Africa. It is very dry, and climate ranges from semi arid in the northeast to extremely arid on the west coast. Vegetation ranges from savanna woodland in the northeast, through savanna to desert in the west and south. Rain-fed crop production is limited to very small parts of the north and northeast. Most land in the country is only suitable for extensive grazing by livestock or wildlife, and rangeland carrying capacities are low. Permanent surface water is restricted to a few rivers on the northern, north eastern and southern borders.

The human population of the country, at 1.7 million, is small, with 30% living in urban centers. The rural economy has two different tenure systems. Forty-three percent of the country, mostly in the drier parts, contains private, medium scale, commercial ranches. Forty-five percent, mostly in the less dry north, is communal land. Communal land is state-owned, but occupied by rural tribal communities—most of the country's population. Communities practice traditional systems of pastoralism in the south and west, and agro-pastoralism in the north and northeast, but their access to markets and infrastructure is poor. In the northeast, among San communities, some sedentary hunting and gathering is practiced.

Wildlife resources of high importance for tourism occur in less densely settled north western and north eastern communal lands. Elephant (*Loxodonta africana*), buffalo (*Syncerus caffer*), hippopotamus (*Hippopotamus amphibius*), sable (*Hippotragus niger*), roan (*Hippotragus equinus*), lechwe (*Kobus leche*), sitatunga (*Tragelaphus spekei*), lion (*Panthera leo*), leopard (*Panthera pardus*) and wild dog (*Lycaeon pictus*) are of conservation importance in the northeast. In the northwest, desert-adapted wildlife species such as elephant, black rhinoceros (*Diceros bicornis*), mountain zebra (*Equus zebra*), springbok (*Antidorcas marsupialis*), kudu (*Tragelphus strepsiseros*), and oryx (*Oryx gazella*) occur. Attractive scenery, enhancing tourism value, exists in both places. Communities were historically not permitted to use these wildlife resources, and were effectively alienated from them. The tendency was for expanding traditional land uses to displace wildlife, and poaching was fairly common. In the 1980s, local nongovernment organizations (NGOs) initiated donor-funded community game guard programs, giving some communities a sense of "ownership" over their wildlife.

(b) *CBNRM in Namibia*

In the late 1960s, Namibia granted *private* landholders custodial rights to manage and use wildlife on their land (Joubert, 1974). The incentives associated with this have resulted in increased wildlife stocks on this land (Barnes & de Jager, 1996). In 1996, a legislative amendment granted similar custodial rights over wildlife to communities on communal land (Corbett & Jones, 2000; Jones, 1995; Jones & Murphree, 2001). This change, part of a national CBNRM program, made it possible for communities to form "*conservancies*," register these, and thus acquire, from the state, partial rights to common property management and use of wildlife in defined areas. By 2001, 14 conservancies had been registered, and some 20 more were in the process of being developed. About five conservancies had drawn up plans for the use and management of their natural resources, mainly wildlife.

The CBNRM program is loosely coordinated from within government and local NGOs, by the Namibia Association of CBNRM Support Organizations (NACSO). Communities are assisted by the local NGOs, donor-funded projects, and a government-backed policy and legislative framework. Funding for this assistance comes mainly from international donors. It takes the form of grants to pay for technical assistance, local NGO facilitation and training activities, and some conservancy recurrent and capital requirements. Since the 1980s communities interested in CBNRM have benefited to varying degrees from donor funds, initially, mainly to employ community members in wildlife protection (community game guards), but also to provide facilitation and training, as well as, lately, capital investments. One aim of CBNRM is for donor inputs to conservancies to be gradually replaced by income from natural resource use, leaving communities self-sufficient. To some extent this has happened, but so far no conservancies are entirely self-sufficient financially, and many receive a significant proportion of their income from donors.

The potential for income generation from natural resources in conservancies is dominated by nonconsumptive tourism (Barnes, 1995a,b), partly through community-owned and run activities (mostly campsites), and partly through joint ventures between communities and private sector investors (lodges and camps). A second important source of income is safari hunting tourism, also involving joint-venture arrangements. Other, less significant and more localized income sources include thatch-grass harvesting, fishing, pole and fuel-wood harvesting, cultural services (traditional villages and shows), crafts production, game meat harvesting and live game sale. Communities bear costs associated with wildlife in the form of damage to crops in agro-pastoral areas and to water points in the drier pastoral areas. Such costs, as estimated from limited empirical research, are documented by Barnes (1995b). They generally amount to less than 5% of wildlife use values. This is a relatively low value, in the broader African context, and it appears to be due to the low productivity of the land for agriculture and livestock, as well as the relatively low human population densities.

CBNRM (or ICDP or CWM) interventions are based on the contention that if communities are allowed to benefit directly from the use of natural resources, then they will have an incentive to invest in and conserve these resources (Barbier, 1992; Callihan & Stuart-Hill, 2000; Child, 1993; Emerton, 2001; Lewis, Kaweche, & Mwenya, 1990; Roe, 2001). Many conservation programs in developing countries now include CBNRM strategies, and they are widely seen as essential for wildlife conservation, particularly outside protected areas. Some workers, such as Gibson and Marks (1995), Barrett and Arcese (1995), Sullivan (1998), and Infield (2001), consider that CBNRM, as practiced in Africa, is inadequate as a conservation and/or development strategy. Problems listed include inappropriate incentive structures, inappropriate distribution of benefits, lack of suitably democratic institutions, intracommunity conflicts, excessive reliance on consumptive wildlife use, excessive reliance on financial benefits from natural resource use, and others. In the case of Namibia's CBNRM program, most of these problems appear to be applicable only exceptionally, or not at all. Design of CBNRM in Namibia has involved care to try and ensure that scale, institutional structures, combinations of resource uses involved, and combinations of economic values captured, are flexible and appropriate to the specific setting.

One unresolved question, however, is a common assertion or suspicion that material benefits, resulting from tourism and consumptive wildlife use in CBNRM, are inadequate to compensate communities for all the costs of investing in wildlife (Barrett & Arcese, 1995; Infield, 2001). Apart from a few studies (Barnes, 1995c; Barnes, Cannon, & Morrison, 2000; Bond, 2001; Jansen, 1990), no rigorous analysis has been done of the financial and/or economic merits of CBNRM as a development strategy. Most discussion about this has had to be conjectural. Our study directly addresses this question, in the context of Namibia.

2. METHODS

Five conservancies were selected as being well enough established, and having well enough developed management plans to allow financial and economic appraisal to be carried out. These were examined as investments, in terms of their value to the community, to the project proponents (financial analysis), and in terms of their value to Namibian society (economic analysis). The analyses are thus primarily *appraisals* of conservancy development plans and projected incomes, rather than *ex post evaluations* of past conservancy performance. But, most of the five conservancies studied have been in the process of development for several years, and the models developed, reflect actual events for these early years.

The analysis needs to be seen in the context of "total economic value" of the wildlife and natural resources, as described by Pearce and Turner (1990) and Emerton (2001). Total economic value embraces direct use, indirect use, and non-use (option, bequest and existence) values associated with natural resources. Direct use values are derived from actual *utilization* of the resource. They contribute tangible value in the form of *income*, and make up the main component of formal economic growth, which is the focus of national development efforts. Indirect use values are derived from ecological or social function (such as erosion protection, waste assimilation, political stability, etc.). Option values reflect the values perceived in retaining the option to use the resource in the future. Bequest values reflect the value perceived in preserving or retaining the resource for others in the future, and existence values reflect the value perceived in retaining the mere existence of the resource.

The focus of this analysis was on direct use values and here we measured the income derived from actual use of natural resources in Namibia. No significant indirect use values were identified and they were not specifically considered. Non-use values were considered, but only as manifested in donor contributions aimed at conserving wildlife in conservancies, as they benefit communities. An example of non-use value would be the income derived through conservancy game guard wages, where these are funded from donors.

As pointed out by Emerton (2001), Adams and Infield (2001), Hulme and Infield (2001), costs associated with wildlife include investments in protection, costs of damage caused by wildlife, and land use opportunity costs. Our analysis focuses on the value of the conservancy as an investment. We developed individual models where the project boundary embraced only the specific *conservancy*, and the costs and benefits directly associated with it. We did not include land opportunity costs, central government investment costs, or benefits associated with forward and backward linkages. These would all be part of broader analyses, for example, of a national CBNRM program, or a national wildlife investment program. But the broader context is discussed in relation to some findings from elsewhere, in Botswana and Namibia. The latter findings suggest that, in most Namibian conservancies, the economic opportunity costs associated with land are low.

(a) *Financial and economic models*

Detailed static and dynamic, budget and cost–benefit spreadsheet models were developed for specific resource use activities within conservancies, and then, making use of these results, for each conservancy as a whole. The benefits of natural resource use were measured, in a cost–benefit framework, against the costs of investing in and undertaking the activity. The project boundary in the conservancy analysis embraced community activities and investment. Thus, where joint ventures between communities and the private sector were involved, only the net benefits accruing to the community from the venture were included in the model.

The models were based on empirical data, gleaned through interviews with wildlife use enterprises and conservancies, through examination of financial data from conservancy operations, and from management plans for conservancies. The data were collected during 1998–2000, and financial values in models were inflated to 2000 prices. The wildlife use and conservancy models measured *financial profitability* (annual net income, financial rate of return, financial net present value) from the point of view of the user or investor. They also measured *economic efficiency* (annual contribution to gross and net national income, economic rate of return, economic net present value), all in economic (or shadow) prices, from the point of view of Namibian society. The conservancy models measured financial profitability from both the community and project perspectives.

Static budget models measured annual financial returns at full production after deduction of all capital and recurrent financial costs including interest and amortization. The dynamic cost–benefit models measured financial and economic returns over five- and 10-year investment periods. Here, interest and inflation were excluded from all calculations. Cost and benefit flows were in constant prices and discounted over time to reflect the time value of money. A real discount rate of 8% was used for both financial and economic models. All capital expenditures were included and depreciation (or appreciation) was accounted for in the residual value of assets in the final year of analysis.

Important economic measures from the static budget models are *gross* and *net national income* (GNI and NNI), as defined by Gittinger (1982). These are the returns in gross and net value added to factors of production owned by Namibian nationals. NNI is GNI minus annual capital asset depreciation. In economic analysis the economic cost, or benefit, to society, of using or producing a resource is taken to be its opportunity cost (the value of its best alternative use). The data are based on financial transactions, but where financial prices differ significantly from opportunity cost, then shadow pricing is applied. Our GNI and NNI measures thus gauge *economic efficiency*, unlike the statistical measures of national income, presented in national accounts.

Shadow pricing, aimed at ensuring that values applied to inputs and outputs reflect their opportunity cost or real scarcity in society (rather than simply market prices), was applied in the economic analyses. Standard criteria for shadow pricing in Namibia are not available, so preliminary ones, developed by Barnes (1994), were used. These were largely modified from standardized ones used in the past in Botswana (Matambo, 1988; Ministry of Finance & Development Planning, 1986), South Africa (CEAS, 1989), and the World Bank (Gittinger, 1982).

Namibia's economy has been relatively open in recent years, with few price distortions, and in many cases market prices fairly reflect opportunity cost. Shadow pricing adjustments were limited to the following. Domestic transfers such as taxes, and subsidies, were eliminated as costs or benefits. Taxes included sales tax, license and permit fees. Subsidies included those from government for live game stocking. All conservancies benefited from grants to assist with capital and recurrent inputs, provided by donors from outside the country. These grants, however, were considered convertible to other applications outside conservancies, within Namibia, and to thus have opportunity costs. They were treated not as subsidies but as costs in the economic analysis.

The models included a detailed stock projection over the investment period, depicting the anticipated growth, or not, of wildlife stocks by species. This incorporated the initial wildlife populations determined from aerial census, the natural growth potential of each species, any purchase/acquisition of stock, any natural immigration of stock, and off-takes. Natural growth potential for each species was calculated using the method of Craig and Lawson (1990) and Spinage (FGU-Kronberg, 1987). This was based on the formula $0.4r_m$, where r_m is the intrinsic rate of increase of the population, and a function of the body weight of the species concerned. Wildlife bio-mass was measured as large stock unit equivalents (LSU), the metabolic equivalent of a 450 kg ox, using the conversion ratios of Meissner (1982). Apart from the financial value of some purchases (subsidized), and some natural immigration from neighboring Botswana (no cost), the value of the stock was made at opportunity cost. In the economic model and the project financial models, the residual value of wildlife stocks in the conservancy, was included within residual assets. In the case of community financial analysis these stocks were not included in residual value (as communities would not be able to recover this stock value at the end of the period).

A general shadow price for unskilled and semi-skilled labor of 0.35 of the market price was applied in the economic models to reflect general unemployment and social pressure for higher wages. A foreign exchange premium of 6% was added to the prices of all tradable items in the economic models, to account for general excess demand for traded and tradable goods and services. In the economic models, inflows from, and outflows to, non-nationals were treated as benefits and costs, respectively. This ensured measurement of *national* income. All economic models included an opportunity cost of capital of 8%, but, as explained above, land opportunity costs were excluded. This allowed direct comparison between model results regarding returns to land. Economic models also did not include national expenditures made by central government in the wildlife or agricultural sectors. Excluded were benefits accruing to private joint-venture partners in the conservancy, or to service providers or producers outside the conservancy. Cost of damage caused by wildlife was included, mainly through inclusion of the costs of mitigating damage. Mitigation costs are used as proxy for damage costs, and thus represent damage costs averted.

All models were tested through sensitivity analysis, by varying key assumptions to determine how robust they were, and the strength of conclusions that can be drawn from the results. The extent to which financial returns differed from the economic ones was used to provide a measure of the influence of policy and/or market imperfections, as described by Jansen, Bond, and Child (1992).

Where values are given in this paper they are in Namibia dollars (N$). At the time of the analysis, in 2000, N$1.00 was equal to US$0.14.

3. RESULTS AND DISCUSSION

(a) *Conservancy profiles*

Table 1 shows some of the features of the five conservancies analyzed. They range from near desert conditions in the northwest (Torra, =/Khoadi //Hôas), via the northern Kalahari (Nyae Nyae), to semi-arid woodlands/floodplain habitats in the northeast (Mayuni, Salambala). They vary greatly in extent from almost a million hectares in Nyae Nyae, where nonwildlife land uses are relatively unimportant to 28 000 ha in Mayuni [2] where half the land

Table 1. *Comparative physical characteristics of the five Namibian conservancies in 2000*

Characteristics	Conservancy				
	Torra	=/Khoadi //Hôas	Nyae Nyae	Mayuni	Salambala
Land area (ha)	352,200	386,000	900,095	28,400	93,000
Core[a] wildlife area (ha)	108,586	177,650	900,095	13,300	11,000
Households (no.)	120	700	700	450	1,200
Mean annual rainfall (mm)	90	150	450	600	650
Rangeland carrying capacity (ha Per LSU equivalent)	30	25	15	12	12
Starting wildlife density[b] (ha Per LSU equivalent)	427	160	464	43	3,875
Expected wildlife density[b] in year 10 (ha Per LSU equivalent)	257	119	251	29	85
Non-consumptive tourism potential	High	Mod high	Mod low	High	Mod low
Safari hunting tourism potential	Mod high	Mod	Mod high	Low	Mod
Consumptive wildlife use potential	Low	Low	Low	Low	Low
Other natural resource use potential	Low	Low	Mod low	Mod	Mod
Livestock keeping potential	Very low	Very low	Mod	Mod	Mod

[a] Core areas, allocated primarily to wildlife (rest of land shared between wildlife and livestock).

[b] Density calculated for the total land area.

is used for fairly intensive agro-pastoralism. Some conservancies possess naturally intact wildlife resources combined with attractive scenery, on at least part of their land (Torra, Mayuni), while in others wildlife resources are depleted and require restocking or investment (Salambala, Nyae Nyae).

In the northwest (Torra, =/Khoadi //Hôas, occupied by Damara communities) the traditional land use is pastoralism, that in the northern Kalahari (Nyae Nyae, occupied by San communities) is hunting and gathering with low-intensity pastoralism, and that in northeast (Mayuni, Salambala, occupied by Mafwe and Masubia communities) is agro-pastoralism. Mayuni is unusual among the five in that it embraces part of a protected area. =/Khoadi //Hôas is unusual in being permitted, by the veterinary authorities, to capture and sell live game animals. The number of households associated with conservancies vary from 120 in Torra to 1200 in Salambala.

(b) *Financial and economic values*

The results of the conservancy valuation are summarized in Table 2. These values give comparisons of the project investment, project income, community income, and the economic value of the conservancy investment. The economic values tell us whether the initiative contributes positively to national development or not. In all cases the conservancies do, with positive annual contributions to gross and net national income, positive net present values, and favorable internal rates of return (all significantly higher than the 8% cut-off rate). For comparative purposes it is useful to separate the conservancies ecologically into those in semi-desert sites (Torra and =/Khoadi //Hôas), those in the mesic northeast (Mayuni and Salambala), and that in an intermediate setting (Nyae Nyae). Land use is generally much less intensive in the semi-desert of the northwest, and relatively more intensive in the woodlands and floodplains of the northeast.

The Torra and Mayuni conservancies stand out as having the most favorable returns, both within their own ecological setting and overall. It is notable that Mayuni, which has access to a dry-season wildlife concentration area with prime tourism potential, has particularly high net benefits per unit of land. The Nyae Nyae and Salambala conservancies are relatively inefficient economically, with lower rates of return and lower net contributions per unit of land. The =/Khoadi //Hôas, conservancy is intermediate in terms of economic value. The differences tend to reflect the balance between the annual net benefits and the capital gains generated by the conservancy. Torra and Mayuni show relatively high annual contributions to national income as well as some overall gains in wildlife stocks. Nyae Nyae and Salambala have low annual net contributions to income, and rely more on net gains in wildlife

Table 2. *Base case financial and economic values for the five Namibian conservancies in 2000 (N$)*

Value	Conservancy				
	Torra	= /Khoadi //Hôas	Nyae Nyae	Mayuni	Salambala
Project financial values					
Initial capital investment	1,190,432	868,586	3,522,521	770,778	1,418,610
Capital investment per ha	3.4	2.3	3.9	27	15
Capital investment per household	9,920	1,241	5,032	1,713	1,182
Annual net cash income	95,300	69,400	−267,100	333,100	133,800
Financial rate of return	16%	19%	15%	8%	8%
Financial net present value[a]	860,800	1,428,500	2,377,400	0	0
Community financial values					
Annual community cash income[b]	406,544	418,556	204,673	732,704	426,058
Cash income per household	3,388	598	292	1,628	355
Cash income per ha	1.2	1.1	0.2	26	4.6
Financial rate of return	133%	205%	23%	220%	40%
Financial net present value[a]	2,133,200	3,350,000	1,364,400	3,696,300	1,347,900
Annual community dividends[c]	228,000	207,900	114,400	225,000	168,700
Dividends per household	1,900	297	163	500	141
Economic values					
Annual gross value added[d]	557,600	503,800	501,600	860,200	525,800
Annual net value added[e]	487,611	459,551	278,621	820,816	455,368
Net value added per ha	1.4	1.2	0.3	29	4.9
Economic rate of return	131%	66%	22%	126%	31%
Economic net present value[a]	3,662,300	4,010,100	4,114,900	4,059,000	2,587,800
Number of jobs created[f]	8	12	26	22	12
Economic capital cost per job	138,394	67,257	177,955	32,025	127,285

[a] Measured over 10 years at 8% discount.

[b] Includes salaries and wages for conservancy employment, net cash income, and dividends.

[c] Annual surplus extracted for distribution to households.

[d] Gross value added to national income at opportunity cost (economic prices).

[e] Gross value added minus asset depreciation.

[f] Permanent formal employment opportunities from conservancy operations, excluding jobs created within revenue sharing and joint-venture tourism operations.

stocks. Both these two conservancies also required significant capital investments in development of these stocks.

The community financial values tell us to what extent the communities have an incentive to invest in the initiative. In all cases the communities can derive very favorable returns on their investments (Table 2). The Torra and Mayuni conservancies are able to earn the most cash income and dividends per household, while the Mayuni, = /Khoadi //Hôas and Torra conservancies, all show very high financial rates of return. The Nyae Nyae and Salambala conservancies provide the least attractive returns for communities. The dominant feature of the community analysis is the fact that donors, and not the communities, bear many of the initial capital and recurrent input costs. All conservancies benefit from donor assistance in this way. Another feature of the community analysis is that it does not incorporate the accumulation of wealth in conservancy wildlife stocks.

The project financial values reflect the returns to the project investor, i.e., the donors, government and community, viewed as one entity. They provide an indication of the broader financial viability of the initiative. Here, all donor contributions are costs, and so are household dividend payments, but increase in the value of wildlife stocks is included as a benefit. Project investors do not, themselves, require large positive returns but seek only to ensure that they do not incur losses, which would require subsidization. As seen in Table 2, the project returns are moderate but generally positive and acceptable.

(c) *Sensitivity analysis*

The degree to which the values measured in the financial and economic analyses are robust in the face of changes in model parameters was tested using sensitivity analysis. This provides an indication of the validity of the conclusions drawn from the results, as well as more information on the characteristics of the investments.

Table 3 provides some results of sensitivity analysis of the Nyae Nyae conservancy model. Variation in capital expenditure, tourism development, wildlife stock densities and stock off-take rates were tested, as well as the inclusion or not of live game sales and stock purchase/acquisition. The economic viability is only weakly affected by significant changes in capital investments. It is also only moderately affected by the changes in wildlife densities and tourism investments, the two of which are closely linked. Replacement of subsistence hunting with live game sale (assuming relaxation of veterinary restrictions) would only slightly enhance the economic value. But, an increase in wildlife off-take intensity, to that approaching the maximum sustainable level, would halt herd growth, reduce the potential for tourism development, and reduce the economic value of the investment. This finding confirms the need for enhancement of wildlife stocks in the conservancy, but enhancement of these stocks through acquisition from within Namibia *reduces* the economic viability of the

Table 3. *The effects of change in some base case parameters on internal rates of return in the Nyae Nyae conservancy financial and economic model in Namibia, 2000*

	Internal rate of return		
	Economic (%)	Financial (project) (%)	Financial (community) (%)
Capital expenditure			
50% of base case	36	25	51
75% of base case	27	19	33
Base case	22	15	23
125% of base case	18	12	16
150% of base case	15	10	11
Tourism development[a]			
No lodges, 2 campsites	11	8	0
1 lodge, 2 campsites	16	11	12
2 lodges, 3 campsites (base case)	22	15	23
3 lodges, 4 campsites	28	19	32
4 lodges, 5 campsites	36	24	40
Wildlife densities			
50% of base case	12	6	14
75% of base case	17	11	18
Base case (251 ha/LSU)	22	15	23
125% of base case	26	19	27
150% of base case	30	22	30
Live game sale			
None (base case)	22	15	23
25% of meat off-take[b]	22	16	24
50% of meat off-take	23	16	25
75% of meat off-take	24	17	26
Stock acquisition[c]			
Base case (447 LSU)	22	15	23
Halved	29	15	22
None	36	15	22
Stock off-take intensity			
Half growth potential (base case)	22	15	23
Maximum-reduced tourism[d]	13	7	14

[a] Different scenarios of tourism development.

[b] Live game capture and sale replaces 25% of subsistence hunting off-take.

[c] Purchase of wildlife stock for release in conservancy.

[d] Initial wildlife stock densities maintained through maximum off-take (tourism growth reduced).

conservancy. These acquisitions carry opportunity costs, which are not sufficiently offset by increased tourism and stock enhancement benefits. The benefits of restocking efforts are likely to have wider and longer term impacts, outside the framework of the specific conservancy analysis and will be reflected through stock enhancement in the neighboring protected and communal areas.

The effect of sensitivity analysis on project financial returns shows patterns similar to those for the economic returns. One difference concerns stock acquisition, which does not reduce the project or community financial values, as it did with the economic value. This is because stock acquisition is generally heavily subsidized. The findings in Table 3 show that community incentives (community rates of return) are moderately affected by variation in capital expenditure. Community incentives are also moderately affected by loss of income earning possibilities caused by low wildlife densities and resultant loss of tourism potential.

Tables 4–6 show some sensitivity analysis results for all the five conservancies. The effects, on economic net value added and community income, of changes in capital costs, and tourism income, as well as inclusion, or not, of consumptive wildlife uses, are shown. Table 4 depicts results for Torra and = /Khoadi //Hôas. Both measures, in both conservancies, are weakly sensitive to changes in capital expenditures. Changes in income from both non-consumptive and consumptive tourism, have a moderate effect on the economic and community values, with the Torra model being a little more sensitive than the = /Khoadi //Hôas one. The = /Khoadi //Hôas values are highly sensitive to the elimination of consumptive wildlife uses, while those of Torra are almost

Table 4. *The effects of change in some base case parameters on net value added and community income in the financial and economic models for the Torra and = /Khoadi //Hôas conservancies in Namibia, 2000*

Torra					
Tourism income[a] (*variation*)	*50%*	*75%*	*Base case*	*125%*	*150%*
Net value added per ha	0.41	0.90	1.38	1.87	2.36
Community cash income per ha	0.35	0.75	1.15	1.56	1.96
Capital costs (*variation*)	*50%*	*75%*	*Base case*	*125%*	*150%*
Net value added per ha	1.63	1.51	1.38	1.26	1.14
Community cash income per ha	1.36	1.26	1.15	1.05	0.95
Meat and live game[b] (*inclusion*)		*Yes*[d]		*No*	
Net value added per ha		1.38		1.06	
Community cash income per ha		1.15		0.88	
Consumptive wildlife use[c] (*inclusion*)		*Yes*[d]		*No*	
Net value added per ha		1.38		0.83	
Community cash income per ha		1.15		0.69	
= /Khoadi //Hôas					
Tourism income[a] (*variation*)	*50%*	*75%*	*Base case*	*125%*	*150%*
Net value added per ha	0.78	0.89	1.19	1.49	1.79
Community cash income per ha	0.74	0.83	1.08	1.83	1.58
Capital costs (*variation*)	*50%*	*75%*	*Base case*	*125%*	*150%*
Net value added per ha	1.34	1.27	1.19	1.11	1.04
Community cash income per ha	1.22	1.15	1.08	1.02	0.95
Meat and live game[b] (*inclusion*)		*Yes*[d]		*No*	
Net value added per ha		1.19		0.44	
Community cash income per ha		1.08		0.46	
Consumptive wildlife use[c] (*inclusion*)		*Yes*[d]		*No*	
Net value added per ha		1.19		0.14	
Community cash income per ha		1.08		0.21	

[a] Tourism here, embraces both non-consumptive tourism and safari hunting.

[b] Embraces all consumptive use of wildlife by communities, but excludes safari hunting.

[c] Embraces all consumptive use of wildlife, including safari hunting.

[d] Base case.

Table 5. *The effects of change in some base case parameters on net value added and community income in the financial and economic models for the Nyae Nyae conservancy in Namibia, 2000*

Nyae Nyae					
Tourism income[a] (*variation*)	*50%*	*75%*	*Base case*	*125%*	*150%*
Net value added per ha	−0.23	0.04	0.31	0.58	0.85
Community cash income per ha	−0.28	0.03	0.23	0.48	0.74
Capital costs (*variation*)	*50%*	*75%*	*Base case*	*125%*	*150%*
Net value added per ha	0.61	0.46	0.31	0.16	0.01
Community cash income per ha	0.62	0.42	0.23	0.03	−0.16
Meat and live game[b] (*inclusion*)		*Yes*[d]		*No*	
Net value added per ha		0.31		−0.19	
Community cash income per ha		0.23		−0.24	
Consumptive wildlife use[c] (*inclusion*)		*Yes*[d]		*No*	
Net value added per ha		0.31		−0.54	
Community cash income per ha		0.23		−0.58	

[a] Tourism here, embraces both non-consumptive tourism and safari hunting.

[b] Embraces all consumptive use of wildlife by communities, but excludes safari hunting.

[c] Embraces all consumptive use of wildlife, including safari hunting.

[d] Base case.

Table 6. *The effects of change in some base case parameters on net value added and community income in the financial and economic models for the Mayuni and Salambala conservancies in Namibia, 2000*

Mayuni					
Tourism income[a] (*variation*)	*50%*	*75%*	*Base case*	*125%*	*150%*
Net value added per ha	14.43	21.66	28.90	36.13	43.37
Community cash income per ha	12.17	18.99	25.80	32.62	39.43
Capital costs (*variation*)	*50%*	*75%*	*Base case*	*125%*	*150%*
Net value added per ha	30.69	29.80	28.90	28.00	27.10
Community cash income per ha	27.33	26.56	25.80	25.03	24.27
Meat and live game[b] (*inclusion*)		*Yes*[c]		*No*	
Net value added per ha		28.90		27.69	
Community cash income per ha		25.80		24.66	
Consumptive wildlife use[c] (*inclusion*)		*Yes*[d]		*No*	
Net value added per ha		28.90		27.69	
Community cash income per ha		25.80		24.66	
Salambala					
Tourism income[a] (*variation*)	*50%*	*75%*	*Base case*	*125%*	*150%*
Net value added per ha	1.27	3.08	4.90	6.71	8.52
Community cash income per ha	1.58	3.08	4.58	6.08	7.59
Capital costs (*variation*)	*50%*	*75%*	*Base case*	*125%*	*150%*
Net value added per ha	5.83	5.37	4.90	4.43	3.96
Community cash income per ha	5.37	4.98	4.58	4.18	3.79
Meat and live game[b] (*inclusion*)		*Yes*[d]		*No*	
Net value added per ha		4.90		4.79	
Community cash income per ha		4.58		4.49	
Consumptive wildlife use[c] (*inclusion*)		*Yes*[d]		*No*	
Net value added per ha		4.90		3.69	
Community cash income per ha		4.58		3.58	

[a] Tourism here, embraces both non-consumptive tourism and safari hunting.

[b] Embraces all consumptive use of wildlife by communities, but excludes safari hunting.

[c] Embraces all consumptive use of wildlife, including safari hunting.

[d] Base case.

not at all. Generally these sensitivity analyses confirm the findings in Table 2, that the Torra investment is economically very efficient and that of =/Khoadi //Hôas, being slightly more vulnerable, is moderately so.

Table 5 shows results for Nyae Nyae and here, it is clear that the economic and community returns are sensitive to capital expenditure changes, highly sensitive to changes in tourism income and extremely sensitive to the exclusion of consumptive wildlife uses. The relative vulnerability of the returns is a reflection of the somewhat weak economic efficiency and financial profitability noted for this conservancy in Table 2. Table 6 shows results for Mayuni and Salambala. Here, the Salambala investment shows itself to be somewhat sensitive to changes in tourism income, and only moderately sensitive to changes in capital expenditures or loss of consumptive wildlife uses. The Mayuni investment is only moderately sensitive to changes in tourism income and very insensitive to changes in capital costs and loss of consumptive wildlife uses. The results confirm the finding in Table 2, that Mayuni is a very attractive investment for Namibian society and the community, while that for Salambala is somewhat less so.

(d) *Discussion*

Our study has shown that conservancy investments in Namibia are economically efficient and contribute positively to national economic well-being. This conforms to the findings of Barnes (1995c) and Barnes *et al.* (2000) for community wildlife use initiatives in Botswana. It refutes the speculative assertion, made by Barrett and Arcese (1995) that wildlife use initiatives are likely to be economically unsound. Our analysis of economic efficiency measures only the return in national income, which reflects direct use value and it does not include international donor grant contributions (which it treats as having opportunity costs within Namibia). This is a reflection of the fact that the project boundary for the economic analysis is around the individual conservancy. Without the specific conservancy, the international donor contributions would almost certainly be spent on wildlife conservation somewhere else in the country, and thus in the national context they can be seen as wildlife *non-use values*. In the national context, therefore, the economic value of CBNRM initiatives is enhanced by the inclusion of these non-use values.

Also excluded from our conservancy economic models are the contributions to national income made by the private component of the joint-venture tourism operations within conservancies. It is debatable whether these should be included within the conservancy project boundary, but if so, they are significant and would enhance the economic efficiency measures.

Our study has also shown that the financial returns for communities from wildlife use initiatives exceed their investments. This similarly refutes the general arguments made by Barrett and Arcese (1995) and Infield (2001), among others, which suggest they may not. But, the generally highly positive returns enjoyed by communities in Namibian conservancies come from two sources. On one hand, they come from utilization of wildlife in the conservancies (mainly through joint-venture agreements in tourism activities) and, on the other, they come via the grants from donors, investing in the CBNRM program. The former, are direct use values (net benefits of wildlife use), and the latter (as discussed above) are effectively manifestations of non-use values (willingness to pay for conservation of the wildlife resources). In as much as both reflect true economic value, and both flow into conservancies as a result of conservancy development, they are both legitimate forms of income for the communities.

Table 7 shows the effects of removal of donor grants would have on the community financial rate of return. These effects are shown with and without the inclusion of the residual value of wildlife stocks, which because they cannot actually realize it, is an intangible benefit for communities. The findings suggest that receipt, by conservancies, of donor grants significantly enhances community returns, but that only in the weakly viable conservancies would their removal jeopardize community financial incentives to participate. In at least three or four of the five conservancies, direct use values alone should be sufficient to attract community investment.

The availability of donor grants, itself, provides an incentive for communities to increase conservancy investment costs. This is happening to some extent in Namibia and the relatively weak viability of conservancies, such as Nyae Nyae, is partly due to the inclusion of nonessential expenditures. Avoidance of these would enhance conservancy economic and financial viability, and should be part of the planning process.

Table 7. *The effect of donor grants (non-use values) on the financial rate of return to communities in the five Namibian conservancies in 2000*

Community financial rate of return	Conservancy				
	Torra (%)	=/Khoadi //Hôas (%)	Nyae Nyae (%)	Mayuni (%)	Salambala (%)
With donor grants without stock[a]	133	205	23	220	40
Without donor grants with stock[b]	44	39	18	24	17
Without donor grants without stock[c]	39	28	1	20	11

[a] Includes income to the conservancy from donor grants, but excludes residual value of wildlife stock appreciation (an intangible value for communities) in benefits.

[b] Excludes income to the conservancy from donor grants, but includes residual value of wildlife stock appreciation (an intangible value for communities) in benefits.

[c] Excludes income to the conservancy from donor grants, *and* excludes residual value of wildlife stock appreciation (an intangible value for communities) in benefits.

As Infield (2001) points out, CBNRM programs have become important in international aid, and this is true for southern Africa. It might be suggested that this partial dependence on donor contributions makes the initiatives unsustainable, but we would argue that for three reasons this is unlikely. First, as shown in Table 7, loss of the donor income does not necessarily eliminate community financial incentives, but only reduces them. Further, as shown below, intangible benefits, such as empowerment, training and improved livelihood security, also provide significant motivation. Second, the donor inputs to conservancies are concentrated in the initial capital, and are focused on building wildlife stocks, institutions and skills, thus establishing the base for a change in land use. Later, further investments by conservancies, based on these sunk costs will have higher returns and will most likely not need enhancement by donors. Third, the donor contributions, in as much as they reflect *non-use values* perceived in developed countries, are likely to persist. Experience over 15 years in southern Africa suggests that the flow of donor funds to CBNRM programs has been enduring. Conservancies designed to capture both use and non-use values, are likely to be sustainable.

Instability in markets for wildlife use activities can affect conservancy sustainability. For example, recent political events in southern Africa have severely affected growth in non-consumptive tourism in parts of Namibia. Tourism income was sharply reduced in some of the conservancies under study. These conditions are likely to be temporary, but the sensitivity analyses presented in Tables 3–6 indicate that conservancy economic and financial efficiency is moderately resilient in the face of them. Safari hunting, and other consumptive wildlife uses, might be severely affected by pressure from animal rights organizations. The sensitivity analyses in Tables 4–6, show that the viability of three conservancies would be resilient, while that of two would be vulnerable, in the face of a ban on consumptive wildlife use. The most successful conservancies are those with several different uses, dominated by non-consumptive tourism.

Ashley (1998) investigated CBNRM initiatives in Namibia, including all of the conservancies analyzed here, for the importance of intangible or non-financial benefits, as these accrue to communities, the natural resource base and Namibian society. She found these to be substantial. The communities benefit from capacity building and empowerment, cultural and aesthetic values associated with wildlife and local traditions, and more secure livelihoods. The latter are linked to the financial benefits described in this paper, but go further in that cash injections from wildlife initiatives fill a critical gap within household coping strategies, and thereby enhance livelihood security (Ashley & LaFranchi, 1997). This complementary role reduces the likelihood of earnings from wildlife being invested in agriculture which could undermine the sustainability of conservancies. Namibia's CBNRM program appears able to capture the potential benefits from including cultural values in community conservation initiatives, as recommended by Infield (2001).

The economic viability as demonstrated in this paper, and the financial incentives available for communities in conservancy development fit in the broader framework of rural or national development. We have not measured the economic efficiency of the CBNRM program as whole, or the wildlife sector as a whole, but evidence from Botswana, where this has been done (Barnes, 2001; Barnes *et al.*, 2000), suggests that the economic viability of individual conservancies extends to the broader context. Conditions in Namibia are very similar to those in Botswana, and thus, allocation of conservancy land to wildlife, and not to other uses, is likely to be economically sound. This is the case largely because both low human population densities and high tourism potential occur together. The situation in countries where wildlife lands have high potential for intensive arable production will tend to be different. Here, if investment in wildlife can be justified at all, more reliance on the appropriate capture of wildlife non-use values would be needed. In any case, more research on the economics of land use allocation is needed.

Namibia's CBNRM program appears to have avoided most of the design flaws and problems which have been highlighted by Barrett and Arcese (1995), Gibson and Marks (1995), Infield (2001), Wells (1995) and Bond (2001). A key feature has been *flexibility* in design (Jones & Mosimane, 2000). This allows conservancies to adopt the locally appropriate scale, institutional design, combinations of resource uses, and to capture appropriate combinations of resource *values* (both use and non-use). Conservancies in Namibia appear able to deliver positive financial incentives to communities, contribute positively to national development, conserve wildlife, and be at least as sustainable as other rural development initiatives. *Ex post* evaluation, using our measures of efficiency and profitability in future years, will confirm whether this is truly so or not.

4. CONCLUSION

(a) Conservancies in Namibia, as constituted and planned, are *economically efficient*. They are able to contribute positively to national income and the development process. The likelihood of their being sustainable is high. Their receipt of donor funding, as part of the national CBNRM program, means that they also provide a channel for the capture of wildlife *non-use values*, as income.

(b) Conservancies also provide *very attractive financial returns for communities*. These returns are made up of income from wildlife use (direct wildlife use values) as well as donor grants (reflecting international non-use values). The latter considerably enhance the attractiveness of conservancy investment for communities, but direct use values alone, can generate positive financial returns. Donor grants perform a very important catalytic role in initiating and speeding up land use change. From the donors' perspective, conservancies also tend to be financially viable.

(c) *Tourism* (primarily nonconsumptive tourism but also safari-hunting tourism) is a particularly important income generator for all conservancies. In the development of tourism, *joint ventures* between private investors, with skills and access to markets, and communities are very important. Other consumptive wildlife and natural resource uses are less important, but they serve usefully to spread risk.

(d) The *existence of natural wildlife populations* on conservancies (reducing the need for investments in stock) is a very significant factor affecting the economic efficiency and financial viability of conservancies. Acquisition of stock for restocking is not economically efficient at the conservancy level, unless there are no opportunity costs involved. It can, however, have wider, longer term economic benefits.

(e) *Flexibility and adaptability in design* has allowed Namibia's conservancy initiatives to embrace an apparently sound rural development framework, which includes significant intangible values and benefits as well as financial income for communities, derived from both use and non-use. The conservancies appear able to deliver positive financial incentives to communities, contribute positively to national development, conserve wildlife, and be at least as sustainable as other rural development initiatives.

NOTES

1. CBNRM projects/programs are sometimes referred to as integrated conservation-development projects/programs (ICDPs) or community-based wildlife management (CWM) projects/programs.

2. For the purpose of this paper, the Mayuni conservancy has been accorded a size of 28,400 ha, which is composed of 15,100 ha in the proper Mayuni conservancy, and 13,300 ha within which the conservancy has tourism rights, in an adjacent protected area.

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Paper IV

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Formal microlending and adverse (or nonexistent) selection: a case study of shrimp farmers in Bangladesh

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Microcredit schemes have become a popular means of improving smallholders' access to credit and making long term investment possible. However, it remains to be explored whether the current microcredit schemes are more successful than earlier formal small scale lending in identifying successful borrowers. We studied shrimp farming in a rural region in Bangladesh where formal microlending is well established, but where more expensive informal microlending coexists with the formal schemes. Farmers – both those who exclusively use formal loans and those who also use informal loans – remain credit-constrained; both types overutilize labour in order to reduce the need for working capital. However, the credit constraint is actually milder for the informal borrowers: the implicit shadow price of working capital is substantially higher in the group that only takes formal loans than in the group that also uses informal loans. These results suggest that informal lenders – with their closer ties to the individual farmers – remain more successful in identifying those smallholder farmers that are most likely to use the borrowed funds successfully. Informal lenders have an information advantage that formal microlenders lack: the latter need to find routes to access this information in order for formal microcredit schemes to succeed.

I. Introduction

In this article, we studied credit markets for smallholder shrimp farmers in Bangladesh. Specifically, we studied whether the increasingly popular small-scale formal credits – microcredits – are reaching those who are most likely to use the borrowed funds successfully. Our findings suggest that this may not be the case. We compared farmers who only borrowed formally with those who also used informal loans and found that, on average, when people only borrowed formally, it was because they were perceived as worse credit risks and were shut off from informal loans, rather than because the formal loans were sufficient to cover their credit needs.

It has long been noted that limited access to credit is an important constraint on rural development in many developing countries, and that there are information problems, selection problems and other problems inherent in the credit allocation process

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(Hoff and Stiglitz, 1993; Hermes and Lensink, 2007). The outcome of these problems, discussed in detail in Section II, is frequently that larger farmers have access to cheap formal credit, whereas smaller farmers are forced to resort to costly informal loans. Because of these problems, many attempts at providing cheap credit to smallholder farmers have failed in the past.

One solution that is gaining popularity is the use of so-called microcredit financing, where various innovative means such as peer monitoring are used to secure loans. The most well-known microcredit organization, the Grameen Bank in Bangladesh, was awarded the Nobel Peace Prize for 2006 jointly with its founder, Muhammad Yunus. Grameen Bank has been in operation since the 1970s. It started in Bangladesh and spread to several other Asian countries, inspiring similar schemes in many developing countries as well. Microcredit schemes have also had a considerable impact on the international development debate. Thus, the United Nations declared 2005 the ‘International Year of Microcredit’, giving some indication of how important this issue is now considered to be for development.

We studied the selection of borrowers by formal microcredit schemes in comparison with traditional informal credit sources in a rural shrimp farming district in Bangladesh. We estimate the shadow prices that farmers are willing to pay for additional credit, an approach which has not been previously used to compare these two forms of credit. Our results indicate that the borrowers who only take formal loans have higher shadow prices for additional credit, and are perceived as worse credit risks, than the farmers who also borrow informally. This suggests that the farmers who only borrow formally are a worse group of borrowers, on average, than the informal borrowers.

The article is structured as follows. Section II provides a theoretical background on the issues surrounding rural microlending, and discusses experiences from the earlier schemes. Section III explains the methodology used in the study. Section IV describes the data set used and provides some descriptive statistics. Section V describes how the analysis was carried out in practice. Section VI presents the results, and the final section discusses the policy implications of these results for rural upliftment strategies.

II. Formal and Informal Credit

Historically, the lack of access to credit has been an important constraint to rural development in developing countries. Microfinance is not the first attempt to address this problem: many developing countries provided cheap, small-scale credit to smallholder farmers in the 1970s. However, these government-run credit schemes were rarely financially viable, and when governments were forced to reduce subsidies in the 1980s, many rural credit schemes collapsed.

To some extent, the problems encountered by such government credit schemes were not surprising. There are a number of reasons why credit markets tend to be more problematic than many other markets, especially in developing countries, and policy interventions that do not take this into account are likely to fail. The main reason why credit markets are more problematic than others is that lenders and borrowers have different information about the quality of the borrower’s project, both with respect to the expected outcome and the variance of the outcome.

Lenders face an adverse selection problem. They can discourage borrowers who have projects with low expected returns by charging high interest rates. However, the borrowers who accept loans with high interest rates are most likely the ones whose projects not only have high risk but also potentially high returns – for the borrower, that is. This means a higher interest rate will increase the share of risky projects in the lender’s loan portfolio and will, at sufficiently high interest rates, reduce the overall return on the loan portfolio (Akerlof, 1970; Stiglitz and Weiss, 1981). Therefore, lenders will normally try to ration credit through other means as well, especially in settings – such as those in many developing countries – where the scope for collecting debt from defaulters is limited, due to weak institutions.

An important alternative way of rationing credit is that lenders can pose high collateral requirements in order to ensure that borrowers will be able to repay loans even if their projects fail. However, high collateral requirements will, of course, tend to make it difficult for smallholders to borrow. Alternatively, lenders can rely on screening procedures by collecting information in order to identify those borrowers who are likely to succeed. However, such information gathering is costly for a bank, and the cost will have to be recouped through increasing the cost of the loan. Since the cost of gathering information is likely to be high – even for the small loans that smallholder farmers might be interested in, the costs of such loans become prohibitively high for small-scale farmers.

On the other hand, informal lenders who pursue lending as a side activity, and who are based within the communities where they lend, can observe individual farmers’ production activities and can more easily identify those who are likely to succeed in their projects. Therefore, such informal lenders have a natural advantage over formal banks. Furthermore, since they have a far smaller adverse selection problem than the formal banks do, and frequently face little competition, they can charge high interest rates on the loans that they provide. Thus, informal credit is characterized by considerably higher interest rates than those seen in formal credit markets, but repayment rates are comparable to those for formal credit.

Attempts to provide cheap credit to farmers through government credit schemes might, in theory, avoid some of the problems encountered by other formal lenders since it is easier for the government than for private lenders to, for example, confiscate land from farmers who do not repay their loans; in practice, however, these advantages have rarely been used. Governments have been reluctant to enforce loan repayments from defaulting farmers. This, in turn, has meant that government credit schemes need subsidies in order to function, and since default rates have frequently increased over time – when other farmers observe that defaulters have not been penalized – most schemes have collapsed at some point (Adams and von Pischke, 1992; Braverman and Guasch, 1993; Armendáriz and Morduch, 2005).

Formal microcredit schemes are an attempt to use social pressure to encourage borrowers to repay their loans. A common setup is that a group of borrowers in the same village or region are made jointly responsible for each other's projects. This moves part of the cost of defaults from the bank to the borrowers. It also reduces the need for screening loan applicants, because neighbours will monitor each others' loan performance and there will be considerable social pressure on individual borrowers to repay loans. By reducing the costs related to small-scale loans, such arrangements enable formal lenders to make cheap loans available to smallholder farmers. The intent is that these loans will enable farmers to make investments and production decisions that would not be profitable at the high interest rates charged by informal lenders, but that become profitable at lower interest rates.

Foreign donors currently show great interest in microfinance. As a result, many microfinance schemes can easily access additional funds and expand their lending. This means that loan recipients who face temporary or long-term problems in repaying their loans can, in many cases, bridge old loans by taking new ones. In other cases, because of the social pressure associated with repaying the loans, loan recipients have settled the amounts they owe by selling some of their property (see, e.g. Copestake *et al.*, 2001). Thus, the high repayment rates that currently characterize many microcredit schemes cannot, in themselves, be seen as indicators of how successful such schemes will be in the longer term, as long-term problems may be masked by short-term increases in available funds or by short-term measures taken by individual borrowers. In addition, in the recent years, many microcredit institutions have increasingly shifted from group lending towards individual lending. For instance, in 2001, Grameen Bank moved to a 'Grameen II' scheme for individual loans. Such institutions have, therefore, become increasingly similar to the older small-scale credit schemes – and presumably risk facing the same problems as their older counterparts.

Given the adverse selection issues which have troubled small-scale formal credit schemes in the past, there should be some attempt to target those farmers who are most likely to use the invested funds successfully. If this is not done, repayment rates are likely to decline in the longer term. Findings from randomized experiments indicate that borrowers selected by microcredit schemes use the funds more successfully than borrowers selected at random (see, e.g. Tedeschi, 2008), which can be seen as a minimum requirement for successful microfinance. However, this finding does not tell us whether formal lenders are as successful in selecting borrowers as informal lenders are. Indeed, the low profitability in many microfinance institutions suggests that they may not be (Cull *et al.*, 2007; Schäfer *et al.*, 2010). The conventional view (Boucher and Guirkinger, 2007) is that formal lending displaces informal lending by making cheaper credit available to farmers who could have borrowed informally in any case. The remaining market for informal lending could then be explained either by the greater flexibility with which unregulated lenders operate, and/or by additional credit needs on the side of borrowers who also borrow formally (Pal, 2002; Hartarska and Nadolnyak, 2007; Barslund and Tarp, 2008). However, an alternative and more problematic outcome could be that there is adverse selection in formal lending, with the result that formal lending reaches farmers who cannot borrow from informal lenders because they are seen as worse credit risks.

Following a theoretical framework originally developed by Bell (1990) and Bell *et al.* (1997), we can visualize the potential outcomes of making cheap credit available to an individual farmer (Fig. 1). We assume that the farmer has a demand for working capital, determined by the profitability of the marginal unit of working capital, and that the farmer can borrow the amount x_f formally at the

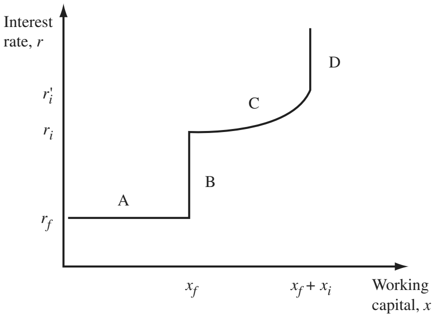

Fig. 1. The supply of working capital available to an individual farmer

interest rate r_f to finance part (or all) of his working capital requirements. If the formal credit is sufficiently large compared with the farmer's demand for working capital, the farmer will make all the investments that are profitable at the interest rate r_f, will not wish to borrow the full amount of formal credit available, and will not borrow informally. This outcome corresponds to the farmer choosing some level of credit along the part of the credit supply curve denoted by A in Fig. 1. The farmer's shadow price of working capital will be equal to the formal interest rate.

If the formal credit is not sufficiently large to achieve this outcome, the farmer will perceive a credit constraint, in that he would prefer to borrow more at the formal rate, and will face a shadow price of working capital that is higher than the formal interest rate. Thus, the farmer will wish to borrow additional funds informally and would be willing, if necessary, to pay a higher interest rate for these additional funds.

Assuming that there is also a market for informal credit in the area, informal lenders will be willing to lend to the farmer, provided that their expected profit from doing so is at least as great as that expected from lending the money to other borrowers. The informal lender's iso-expected profit curve with respect to the size of the loan will be convex: it declines initially with the size of the loan because of the fixed costs associated with gathering information on the borrower, but it increases with further increases in loan size because of the increased risk of default associated with larger loans.

This means that an individual farmer will face an upward-sloping supply curve of informal credit, specific to that particular farmer, and determined by the informal lenders' perception of him/her. Bell (1990) shows that, depending on how competitive the informal market is, there is likely to be a credit constraint in the informal market as well, such that the farmer cannot borrow additional funds above some credit ceiling x_i.

We observe that there are several possible outcomes. If, after borrowing the full formal amount available, the farmer's shadow price of working capital is lower than the informal interest rate facing that specific farmer, he will still not borrow informally. This outcome corresponds to a level of credit along the part of the credit supply curve denoted by B in Fig. 1. The shadow price of working capital will be higher than the formal interest rate, but lower than the informal interest rate available to that farmer.

If the demand for working capital is sufficiently high, the farmer will also borrow informally. If the amount of informal credit made available is large enough to cover his working capital needs at the informal interest rate, the farmer will perceive a shadow price of working capital that is equal to the informal interest rate that he is paying. This outcome corresponds to a level of credit along the part of the credit supply curve denoted by C in Fig. 1. The farmer borrows x_f formally and combines this with additional informal funds.

When the informal credit constraint is also binding, the farmer borrows the total working capital $x_f + x_i$. However, even at the higher informal interest rate r_i', the farmer would prefer to borrow more than this amount. He, therefore, perceives a shadow price of working capital which is higher than the informal interest rate. This corresponds to section D of the credit supply curve shown in Fig. 1.

In all the four cases, cheap formal credit generates a welfare improvement for the farmer because his overall borrowing costs are reduced. However, it is only in case A that the farmer's investment decision will be directly determined at the margin by the formal interest rate. In all the other cases, the farmer's marginal investment decision will be determined by the relationship between his shadow price of working capital and the interest rate that informal lenders offer. Since this informal rate will vary from farmer to farmer, it means the farmer's shadow price of capital and, hence, the related marginal investment decision will be determined by how the farmer is perceived as a credit risk by informal lenders.

If a farmer faces a constraint on formal credit, but nonetheless chooses not to borrow informally, this is because his shadow price of working capital is lower than the informal rate that he is offered. We should note that the informal rate offered to this farmer is determined by the informal lenders' expected profit from lending to him rather than to other farmers. Thus, if the farmer's shadow price is higher than the average informal interest rate, this indicates that the farmer is perceived as a poor credit risk by informal lenders. He would be prepared to borrow at the informal interest rates offered to other farmers, but is not offered the latter because the informal lenders' expected profit from doing so is less than the expected profit from lending to other borrowers at that rate. In this case, the farmer does not borrow informally because informal lenders are reluctant to lend to him/her, and the formal lender has made a poor choice when lending to this borrower rather than to others.

On the other hand, if the farmer's shadow price of working capital is lower than the informal interest rates offered to other farmers, the farmer's main reason for not borrowing informally is that the formal credit takes care of most of his working capital needs. In this case, the farmer could (presumably) borrow informally at rates comparable to those offered to other farmers, but chooses not to do so because it would not be profitable.

Thus, we can study the adverse selection issue in formal lending by looking at whether farmers who only borrow formally have higher or lower shadow prices of working capital (and, hence, are perceived as worse or better credit risks) than the farmers who also take informal loans. If farmers who only borrow formally have an average shadow price of credit which is lower than the average informal interest rate, this means that formal credit has displaced informal lending and that the formal borrowers' main reason for not borrowing informally is that their credit needs have been met by formal loans. On the other hand, if formal borrowers have an average shadow price of credit which is higher than the informal interest rate, this means that they are unable to borrow because they are perceived as worse than average credit risks.

In order to analyse these issues, we studied the shadow prices for working capital among shrimp farmers in a rural region in Bangladesh where formal and informal small-scale credit schemes coexist. Some farmers in the study only used small-scale formal loans, a few used only informal loans and some used both types of loans. Investigating whether there are systematic differences in shadow prices between borrowers who use only formal loans and those who also (or only) use informal loans, indicates how successful formal schemes have been in identifying farmers who are perceived as good credit risks.

If there are indeed differences in behaviour between the two groups of farmers, one potential explanation might be that there are differences in the technologies that they use.[1] If this is the case, there might be different ways of looking at this from a policy perspective. On the one hand, it might be desirable for formal microlenders to target farmers who use the most appropriate technology (because they are most likely to use the funds successfully). On the other hand, it could also be argued that the formal microcredit schemes should target those farmers who use less appropriate technologies in order to provide them with funds that can enable them to upgrade to better technologies. Because differences in technology between the two groups can be interpreted in different ways, such differences need to be disentangled from the issue of shadow prices for credit, which is the focus of this study. Thus, we need to examine technological differences separately.

III. Shadow Prices

In order to estimate the shadow price of capital, we apply a shadow price approach originally developed by Lau and Yotopoulos (1971) for use in efficiency measurement. The basic assumption behind this approach is that firms optimize with respect to shadow prices rather than observed market prices. These shadow prices are normally interpreted as measuring allocative inefficiencies due to poor input choices. The approach also allows farmers to be technically inefficient, i.e. they may not all use the best possible technology. However, in a situation such as that studied here, where most or all farmers are constrained in their use of one or several inputs, farmers will in fact optimize with respect to shadow prices rather than market prices even when they are allocatively efficient. If one assumes that there are no inefficiencies other than those caused by the input constraints, the estimated shadow prices can then be seen as measuring the actual shadow prices facing the individual farmer, rather than as measuring how inefficient the farmers are in their input use.

We assume that, apart from credit markets, the environment for shrimp farmers in rural Bangladesh can be characterized by competitive markets. Output is assumed to be demand-driven, with the result that input prices and output can be considered as exogenous. This makes the cost function an

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[1] Balcombe *et al.* (2008) studied technical efficiency among rice farmers in Bangladesh and found that, on average, farmers who had no access to credit at all were less technically efficient than farmers who had access to credit. However, the authors did not separate farmers with credit access by the type of credit used, making comparison between formal and informal borrowers impossible.

appropriate behavioural function. In order to examine whether there are systematic differences in the technology farmers employ, we used an input-oriented measure of *technical efficiency*, defined as the ability to minimize the input use for producing a given output. The underlying production function can then be specified as

$$y = f(\phi x; \beta)\exp\{v\} \tag{1}$$

where y is the farmer's scalar output, x the input vector, $f(\phi x; \beta)$ the deterministic part of the production function, β a vector of parameters in the production function, v a symmetrically distributed stochastic error term with mean zero and constant variance, and $0 \leq \phi \leq 1$ a measure of technical efficiency that can cause the cost function to shift (Kumbhakar and Lovell, 2000).

As the farmers are assumed to minimize cost with respect to shadow prices rather than observed market prices, the first-order condition relates the marginal rate of transformation to the relative shadow price, expressed as

$$\frac{\partial f(\phi x, \beta)/\partial \phi x_2}{\partial f(\phi x, \beta)/\partial \phi x_1} = \theta_{21}\frac{w_2}{w_1} \tag{2}$$

where w_i is the observed market price of factor i, θ_{21} a measure of the shadow price adjustment to the relative market price of factor 2 in terms of factor 1 and $\theta_{21}w_2/w_1$ the relative shadow price of factor 2 in terms of factor 1. If $\theta_{21} = 1$, the farmer optimizes with respect to the observed relative market price. If $\theta_{21} < 1$, it means that the farmer optimizes with respect to a relative shadow price of factor 2 which is lower than the observed relative market price of that factor. The opposite is true if $\theta_{21} > 1$. In the following, the price of the first input (labour) is set as a numeraire.

IV. Data

This study uses data from a survey of credit sources used by shrimp farmers in the Khulna District in Bangladesh. The survey was carried out in late 2004, and included questions on the farm's production of shrimp and other outputs as well as on the prices paid for these outputs. A number of questions addressed the farm households' demand and supply of inputs to production: the use of labour (own and hired) in farm production, wages paid to hired labour, the supply of labour for paid work elsewhere by the household and wages received for the latter; and the use of land (own and leased), payment for leased land, leasing out of land and payment for the latter. The survey also included questions about household characteristics such as household size and education (if any). Finally, the survey asked about formal and informal loans taken, the purpose of the loans, the interest paid on each loan and whether households were credit-constrained in the sense that they would have liked to borrow more.

For the subdivision between *formal* and *informal* loans, we follow the standard practice of defining *formal lenders* as institutional lenders such as banks and microcredit schemes, which mainly finance loans through deposits from others. *Informal lenders* are defined as private lenders such as middlemen in the shrimp sector, rich villagers or relatives of the farmer, who mainly finance loans out of their own equity. In practice, this subdivision was straightforward to make.

In all the villages surveyed, there were functioning labour markets, land rental markets and credit markets for working capital. All households were assumed to be price takers in the sense that, although different households faced different input prices (depending, for example, on whether they were net buyers or sellers of the input), it is assumed that none of them were able to affect the input prices that they paid or received for the marginal unit purchased or sold. Thus, although many of the households had access to favourable prices on, for example, family labour from close relatives, it was assumed that the highest input price paid reflected the marginal input cost facing each household, and that this price was unaffected by the household's demand for the input.

Similarly, it was assumed that, for those households that rented out labour or leased out land, the marginal value of such labour or land in own production was the price paid for it (because, presumably, the household would have used more of the labour or land in its own production if it had been more profitable to do so). If these price-taking assumptions hold, farm production decisions will be based solely on the prices of the marginal unit of each input. Thus, although the farm household is likely to make consumption, work and production decisions jointly in practice, production decisions can nonetheless be analysed separately from the household's other decisions (Sadoulet and de Janvry, 1995).

Since the purpose of this study was to compare informal and formal loans for use in production, farmers who had borrowed for consumption purposes or who had not borrowed at all – approximately half the surveyed farmers – were removed from the sample. Descriptive statistics over borrowed capital, labour use, land use and agricultural production for the farmers remaining in the data set are given in Table 1. All farmers perceived themselves as

Table 1. Descriptive statistics over borrowed capital, labour use, land use and agricultural production

	Farmer groups							
	Formal loans only				At least some informal loans			
Variables	Average	SD	Maximum	Minimum	Average	SD	Maximum	Minimum
Borrowed working capital (takas)[a]	23 571	32 988	150 000	3500	52 917	61 327	190 000	1000
Average rate of interest (%)	13.6	5.3	24.2	5.0	24.4	19.2	60.0	2.6
Marginal rate of interest (%)	14.3	5.9	28.0	5.0	34.6	19.8	60.0	6.0
Labour used in agriculture (hours per year)	17 065	13 147	53 782	3483	19 419	18 919	84 634	2731
Own labour supply, share of total labour use	1.01	0.43	1.78	0.17	1.08	0.40	1.67	0.16
Marginal cost of labour	10.6	3.4	18.8	1.0	13.1	12.1	59.2	0.6
Land use (bighas)[b]	30.9	47.4	200	0.5	39.3	65.6	250	1.0
Own land, share of land used	0.73	0.46	1.60	0.00	0.76	0.45	1.60	0.00
Marginal cost of land (takas)	357	39	430	300	344	30	400	324
Shrimp production (kg)	762	1545	8010	10	636	843	2520	20
Rice production (maunds)[c]	149	153	640	0	86	86	280	0
Conversion factor, rice to shrimp	1.15	0.20	1.60	0.81	1.14	0.32	2.22	0.80
Fish production (kg)	736	1534	8000	10	373	394	1280	20
Conversion factor, fish to shrimp	0.15	0.06	0.40	0.07	0.17	0.12	0.60	0.04
Vegetable production (takas)	1196	4038	20 000	0	389	1145	4000	0
Conversion factor, vegetables to shrimp	3.2E–3	0.5E–3	4.0E–3	2.4E–3	3.3E–3	1.0E–3	6.7E–3	2.0E–3
N	28				18			
Share of total sample	0,61				0,39			

Source: Own survey.

Notes: For 'Own labour supply, share of total labour use' and 'Own land, share of land used', the share is greater than one when some of the labour or land is rented out and, hence, is not used in own production.

[a] 1 taka ≈ 0.015 US dollars; [b] 1 bigha ≈ 1350 m^2; and [c] 1 maund ≈ 40 kg of rice.

credit-constrained: they all stated that they would have liked to borrow more money at the prevailing interest rate. This means that they can all be assumed to have borrowed the full amount that they were able to. This simplifies the analysis considerably (see, e.g. Feder *et al*., 1990 or Dutta and Magableh, 2006, for discussions of the additional complexities involved in estimation when this is not the case). Furthermore, with the framework used in Section II, this also implies that all the farmers belong either to Category B (credit-constrained, and financing all working capital requirements with formal loans) or Category D (credit-constrained, and financing at least some working capital requirements with informal loans). The fact that even farmers who borrow informally are credit-constrained indicates (following the reasoning in Bell, 1990) that competition among informal lenders is limited.

Some 61% of the studied farmers took only formal loans, 9% took only informal loans and the remaining group (30%) took both formal and informal loans. Since the crucial distinction in our analysis is that between farmers who do not borrow informally and those who do, the two groups of farmers who borrow informally (whether they also borrow formally or not) are equivalent for the purposes of our study and are aggregated in the analysis.

The average rate of interest paid by the farmers taking only formal loans was 13.6%. If one looks at the interest paid by each borrower on the last taka[2] of formal loans (the marginal factor cost for formal loans), the marginal cost of capital was, on average, 14.3%, i.e. almost the same. On the other hand, for farmers who also used informal loans, the differences in interest rates between the two types of loans meant that the marginal rate of interest on the last taka borrowed was substantially higher than the average rate of interest paid. The average rate of interest paid by these farmers was 24%, but the marginal rate of interest on the last taka borrowed was, on average, 35%.[3]

The two categories show largely similar patterns in terms of labour use. Both groups mainly use own labour, but both groups have farmers who, to some extent, supplement this with hired labour. Many households also supply labour outside of agricultural production, either by doing own off-farm production as a side activity or by working for pay elsewhere. The average farmer in both groups is a net supplier of labour, in that own labour supply is slightly larger than on-farm labour use, but there is considerable variation within both groups. Average labour costs are difficult to calculate, since unpaid family labour (and low-paid labour from relatives) plays an important role on most farms. For the last labour hour used on each farm, the informal borrowers faced somewhat higher labour costs on average. There is also considerable variation in the marginal labour costs faced within both groups.

Land rental markets are well developed and both groups include farmers who rent land to or from others. On average, the surveyed farmers rent more land from than to others, but again the variation is considerable in both groups.

Shrimp farming was the main farming activity on all the farms surveyed, although it was not necessarily the main economic activity of the household. Many farms supplemented shrimp production with other agricultural production during other parts of the year. The main side activity was rice production, but many farmers also devoted time and resources to fish breeding, vegetable production or both. It may be noted that although both groups display considerable variation, the average shrimp production is lower among farmers who cover at least some of their working capital requirements through informal loans, and that the variation is smaller in this group than among the formal borrowers.

V. Econometric Specification

In order to measure the shadow prices of working capital facing each group of farmers, a number of methods could potentially have been used. In principle, the farmers in our sample carry out a multi-input, multi-output farming activity. However, the standard methods normally used in efficiency measurement for such activities were unsuitable for our purpose. Distance functions, such as those discussed in Färe and Primont (1995) or Fernández *et al.* (2005), do not permit direct measurement of shadow prices, which was the main topic of interest for our study. These methods have primarily been developed to measure technical, rather than allocative, efficiency. Profit efficiency measurement would, in principle, have permitted the estimation of shadow prices (Kumbhakar and Lovell, 2000), but given the situation in the region studied, these methods would have been problematic in practice. They would have entailed valuing all inputs and outputs at market prices. However, as noted, farmers supply most of

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[2] Bangladeshi currency; 1 taka ≈ 0.015 US dollars.

[3] The lowest interest rates were in fact also found among the informal borrowers: a few farmers had borrowed informally from relatives at low rates.

their inputs of labour and land themselves, at lower-than-market prices. Many of them would be recorded as making net operating losses if all inputs and outputs were valued at market prices, making the standard econometric specifications used in profit function approaches problematic.

In this article, therefore, we assume a Cobb–Douglas cost function. In the absence of shadow price adjustments, this cost function can be written as

$$c(y, w; \beta) = \gamma_0 y^{1/r} \prod_n w_n^{\gamma_n} \tag{3}$$

where c is the production cost, y agricultural production,[4] w_i the input prices (w_1 is the hourly wage rate, w_2 the interest rate on borrowed working capital and w_3 the land rent) and r indicates the degree of homogeneity in the underlying production function. The restriction that $\sum_n \gamma_n = 1$ is imposed to satisfy the assumption of homogeneity of the cost function with respect to input prices.

Following Kumbhakar and Lovell (2000), the possibility of differences in technical efficiency is introduced into the model by replacing the intercept of the cost function by $\gamma_0 \exp(-\Delta D)$, where D is a dummy variable set to 1 if the farmer belongs to a particular group and 0 otherwise. Thus, exp $(-\Delta)$ is the relative technical efficiency of this group compared to the other group. Furthermore, farmers are assumed to minimize costs with respect to shadow prices rather than market prices. The input demand equations are then given by

$$\begin{aligned}
\ln x_1 &= \ln \gamma_0 - \Delta D + \ln \gamma_1 + \frac{1}{r} \ln y \\
&\quad + \gamma_2 \ln\left[\theta_{21}\left(\frac{w_2}{w_1}\right)\right] + \gamma_3 \ln\left[\theta_{31}\left(\frac{w_3}{w_1}\right)\right] \\
&= \ln \gamma_0 - \Delta D + \ln(1 - \gamma_2 - \gamma_3) + \frac{1}{r} \ln y \\
&\quad + \gamma_2 \ln\left[\theta_{21}\left(\frac{w_2}{w_1}\right)\right] + \gamma_3 \ln\left[\theta_{31}\left(\frac{w_3}{w_1}\right)\right] \\
\ln x_2 &= \ln \gamma_0 - \Delta D + \ln \gamma_2 + \frac{1}{r} \ln y \\
&\quad + (\gamma_2 - 1) \ln\left[\theta_{21}\left(\frac{w_2}{w_1}\right)\right] + \gamma_3 \ln\left[\theta_{31}\left(\frac{w_3}{w_1}\right)\right] \\
\ln x_3 &= \ln \gamma_0 - \Delta D + \ln \gamma_3 + \frac{1}{r} \ln y + \gamma_2 \ln\left[\theta_{21}\left(\frac{w_2}{w_1}\right)\right] \\
&\quad + (\gamma_3 - 1) \ln\left[\theta_{31}\left(\frac{w_3}{w_1}\right)\right]
\end{aligned} \tag{4}$$

where x_i are the quantities of inputs; x_1 total number of labour hours per year, x_2 the total amount of borrowed working capital and x_3 the land used in production, measured in bighas.[5] In the first of these equations, the $\ln(1 - \gamma_2 - \gamma_3)$ term is highly nonlinear and a fourth-order Taylor expansion was used instead.

In order to see if there was a difference in shadow prices between farmers who only took formal loans and those farmers who took either only informal loans or used both types of loans, we follow Stefanou and Saxena (1988), Kumbhakar and Bhattacharyya (1992), Bhattacharyya *et al.* (1994) and Wang *et al.* (1996), and model the shadow prices and the technical efficiency parameter as functions of firm specific variables, as follows:

$$\Delta D = \alpha \cdot \text{informal} \tag{5}$$

$$\begin{aligned}
\theta_{n1} &= \exp(\beta_n + \beta_{\text{inf},n} \text{ informal}) \quad n = 2, 3 \\
\theta_{11} &= 1
\end{aligned} \tag{6}$$

where informal is a dummy variable which is set to 1 if the farmer has taken any type of informal loans, and 0 if only formal credits have been used.

VI. Results

Since the demand equations in the equation system (Equation 4) have correlated disturbances and cross-equation restrictions, the system was estimated using a nonlinear, seemingly unrelated regression technique (Zellner, 1962). The motivation for using this method is that it makes better use of the information than if the equations had been estimated separately. Table 2 gives the parameter estimates.

From Table 2, the R^2 measures for the individual equations range from 0.51 to 0.82. There is no indication of any difference in technical efficiency between the two groups, which simplifies the analysis of the remaining results. The results indicate that there are substantial economies of scale; thus, being able to access additional inputs should increase profitability considerably.

The results indicate that both groups optimize with respect to shadow prices rather than with observed market prices. The results also indicate that there is a significant difference in the relative shadow prices used by those farmers who only rely on loans from

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[4] For the reasons discussed previously, we chose not to use a multi-output framework. Instead, for each farmer, the market prices facing that specific farmer were used to recalculate the production of rice, fish and vegetables into the number of kilograms of shrimp that would yield the same revenue. Essentially, this means that we use an output variable y where the unit of measurement is kilograms of shrimp equivalents.

[5] A standard unit of area used in Bangladesh. A *bigha* is defined as one-third of an acre, i.e. approximately 1350 m^2.

Table 2. Results

Parameter	Coefficient
$\ln \gamma_0$	2.64** (0.84)
$\ln \gamma_2$	−2.43** (1.05)
$\ln \gamma_3$	−0.64** (0.18)
α_1	0.091 (0.15)
$1/r$	0.66** (0.048)
β_2	2.38** (1.18)
$\beta_{\inf 2}$	−1.29** (0.33)
β_3	1.57** (0.37)
$\beta_{\inf 3}$	0.35 (0.28)
R^2 labour	0.57
R^2 capital	0.51
R^2 land	0.82

Notes: SEs are reported in parentheses.
** Denotes significance at the 5% level.

formal lenders, and the prices used by those farmers who take at least some loans from informal lenders. The estimated values of θ_{21} and θ_{31} are larger than unity for both groups, suggesting that the farmers overutilize labour in relation to both land and working capital.

From the parameter estimates, it can be seen that the over-allocation of labour in relation to working capital is significantly smaller in the group using informal credit. The shadow price of working capital is substantially higher in the group that only takes formal loans (154% on average) than in the group that also uses informal loans (103% on average), even though the market interest rate (as given in Table 1) is considerably lower for the formal loans.

VII. Conclusions

This study has analysed differences in the shadow price of working capital between shrimp farmers who rely on formal credit for all their working capital needs and farmers who also borrow informally. The sample was small, and the results may not be representative for the overall formal and informal markets for small-scale credit schemes. However, some results from the study nonetheless deserve some attention.

All the farmers in our sample perceived themselves to be credit-constrained; this was true for those who financed all their working capital through formal borrowing as well as for those who also borrowed informally. This is supported by the finding that both groups act as though the shadow price of working capital is substantially higher than the price they actually pay. Thus, improved access to working capital credit remains an important issue for rural smallholders, even in Bangladesh, where formal microcredit schemes have been in operation for a considerable length of time.

The farmers who borrow informally faced lower shadow prices for working capital than those who only borrowed formally. This indicates that, when farmers only borrow formally, it is not because the formal credit is sufficient to meet their credit needs and reduce their shadow prices of credit to levels lower than the prevailing informal interest rates; rather, it is because they are perceived as worse credit risks than the informal borrowers, and can only borrow informally at interest rates higher than those facing other farmers. Thus, at least in this part of Bangladesh, the formal credit schemes currently available to smallholder farmers have not been successful in selecting the farmers who are most likely to use the borrowed funds successfully.

Formal microcredit schemes are an important improvement compared with previous attempts at providing formal credit to small-scale rural farmers, in that repayment rates are far better. This means that, unlike previous formal credit schemes aimed at smallholder farmers, microcredit schemes are likely to remain financially viable and, hence, continue to be available as a source of credit for the foreseeable future. As noted in Section II, the availability of cheap working capital through formal microcredit schemes represents a welfare improvement for farmers, even when the cheap working capital is not large enough to have a direct impact on their production decisions. It is also likely that the competition from formal microcredit schemes leads to lower interest rates in the informal credit market, with additional effects on welfare and investments among farmers. In addition to this, formal credit may be reaching borrowers who are excluded from the informal credit market because of discrimination rather than because they are perceived as poor credit risks.

Nonetheless, the indication from our study is that work still remains to be done in identifying the most suitable borrowers, and to make sure that they have access to the amount of credit that they need. The informal lenders have better information on individual borrowers, and therefore remain more successful than the formal credit sources in assessing what borrowers are likely to make the best use of additional funds. Finding ways of making this information available to formal lenders remains an important issue.

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