Switching On:
Cambodia’s Path to Sustainable Energy Security

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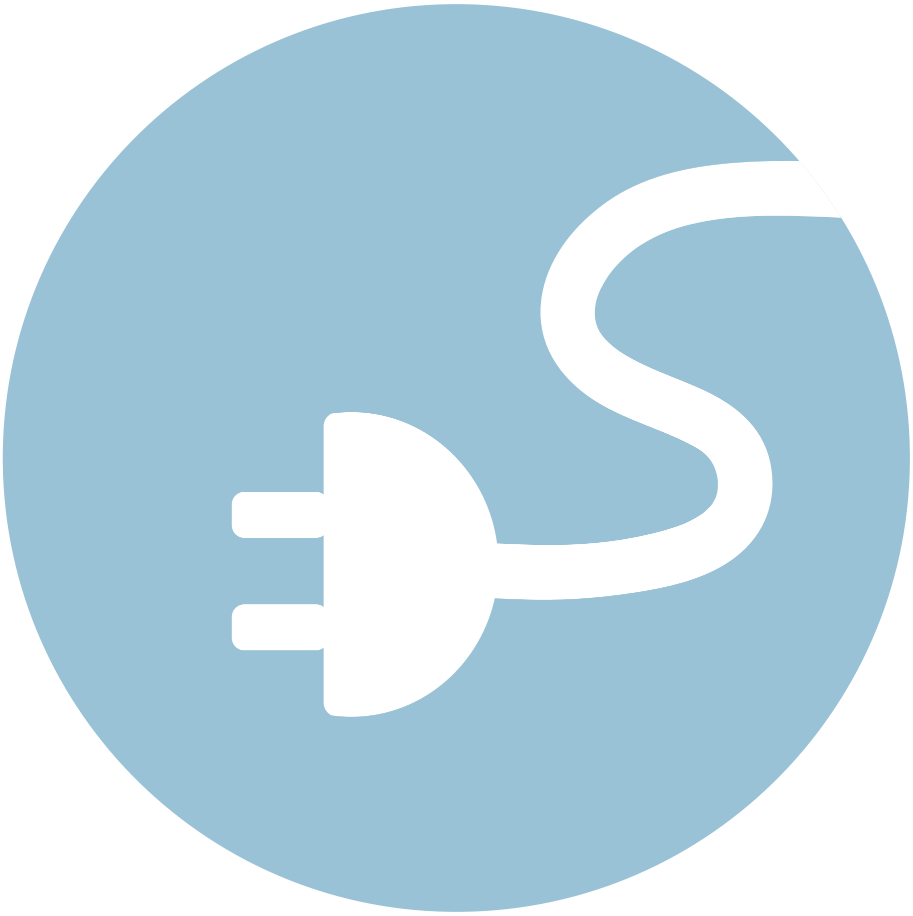

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Table of Contents

Executive Summary

This report investigates the potential for Cambodia to diversify its power supply technology mix, for greater energy security and sustainability benefits, given changing technology cost relativities. To date almost all Cambodian investment in the power sector has focused on largescale hydropower and coal-fired generation. The Royal Government of Cambodia (RGC) has indicated investing in sustainable energy is a priority [1]: recent technology cost developments mean the RGC can pursue energy security, access, reliability and affordability goals, at least in part, through increased investment in (non-large hydropower) renewable energy.

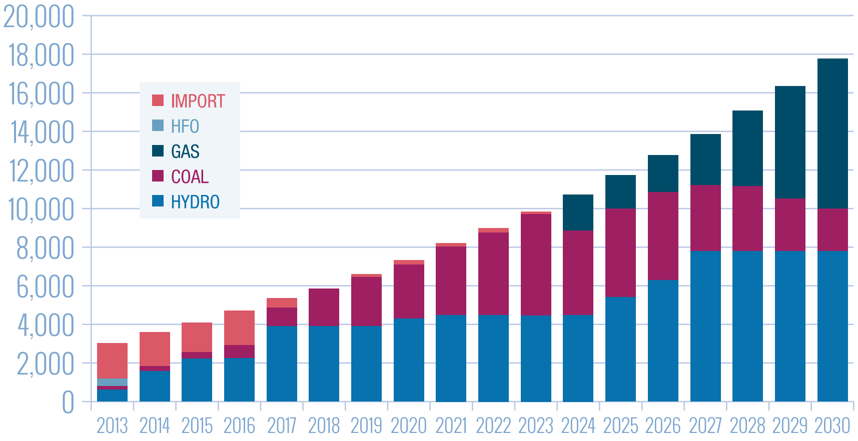
Cambodian power sector – context

The power sector in Cambodia, with domestic generation supply of around 3000 gigawatt hours (GWh) in 2015, is small compared with its ASEAN neighbours Thailand and Vietnam, but it is growing very rapidly. Generation capacity increased from 308MW in 2009 to 1584MW at end-2014, [2] accompanied by significant construction of a national grid network. This has contributed to the RGC making steady progress towards its overarching electricity access targets (100% of villages to be electrified by 2020 and 70% of households by 2030). Electricity consumption in Cambodia has also been growing very rapidly – with overall demand growth averaging nearly 20% per annum since 2010. This has largely been due to continuing rapid economic growth, notably in the electricity-intensive garment sector, and the extension of the national grid to more of Cambodia's population.

From 2018, the Ministry of Mines and Energy (MME) expects (Figure 1) power imports to have been reduced significantly as a proportion of electricity supply and to be able to meet demand almost entirely through domestic generation. MME demand projections are, however, based on a lower demand growth rate than has been evident since 2010.

Part of achieving lower demand growth will be implementing Cambodia's draft energy efficiency strategy [3], involving a range of actions including to introduce performance standards for the construction sector, industrial equipment and home appliances. If demand does not fall as rapidly as anticipated there may still be a need for additional electricity supply (potentially 1000 gigawatthours (GWh)) beyond MME's expected domestic generation supply in 2020 (around 7600 GWh).

FIGURE 1:
RGC forecast to 2030 for electricity supply (in GWhrs) by fuel mix type



Source: MME, September, 2015

While RGC has indicated that growing the power sector in an environmentally sustainable way is a key priority, to date investment in (non-large hydro) RE has yielded generation capacity in the order of 35 MW, compared with over 1200 MW put in place under Cambodia's Power Development Plan (PDP) since 2009. RGC planning for future investment in generation capacity currently remains focused on large hydropower and fossil fuel-fired technologies – which have considerable environmental impacts (and therefore external costs). Cambodia's PDP forecasts (to 2030, Fig.1) do not currently factor in any significant contribution from (non-large hydro) RE generation even though solar and biomass generation can offset low hydropower output in dry season. Rapidly falling renewable energy technology costs mean Cambodia can cost-effectively strengthen its energy security by balancing proposed investment in large-scale hydro and fossil generation with accelerated investment in solar and biomass technologies.

Global energy transition: dynamics and opportunities

Utilities, consumers and investors in developed and developing countries are switching to renewable energy to constrain environmental impacts and reduce the regulatory risk of emissions limits and carbon pricing but also because it is increasingly economic in its own right. Increasing scale is a driver of rapid declines in cost: globally, the installation cost (averaged) of wind and solar fell 28% from 2011 to 2014.

In particular, the following prices for utility scale solar and wind generation, achieved in Chile and China in 2015, were competitive against all fossil fuel and large hydro technology bids:

Costs are expected to continue falling in coming years due to increasing economies of scale, more efficient designs, and advances in materials and manufacturing. Technological developments such as affordable residential-scale storage devices will also increase the utility (and therefore competitiveness) of rooftop solar. The falling cost of consumer solar and storage raises the prospect of consumers disconnecting from the grid or using the grid for backup. As costs fall and incomes rise Cambodian households and businesses are also likely to become power producers within the next decade.

FIGURE 2:
2015 wind and solar costs [4]

Utility solar (global)	Wind 100 MW (China)	Overnight solar (Chile)	Wind (Chile)
6-8 ¢/kWh	4.5 ¢/kWh	9.7 ¢/kWh	7.8-9.5 ¢/kWh

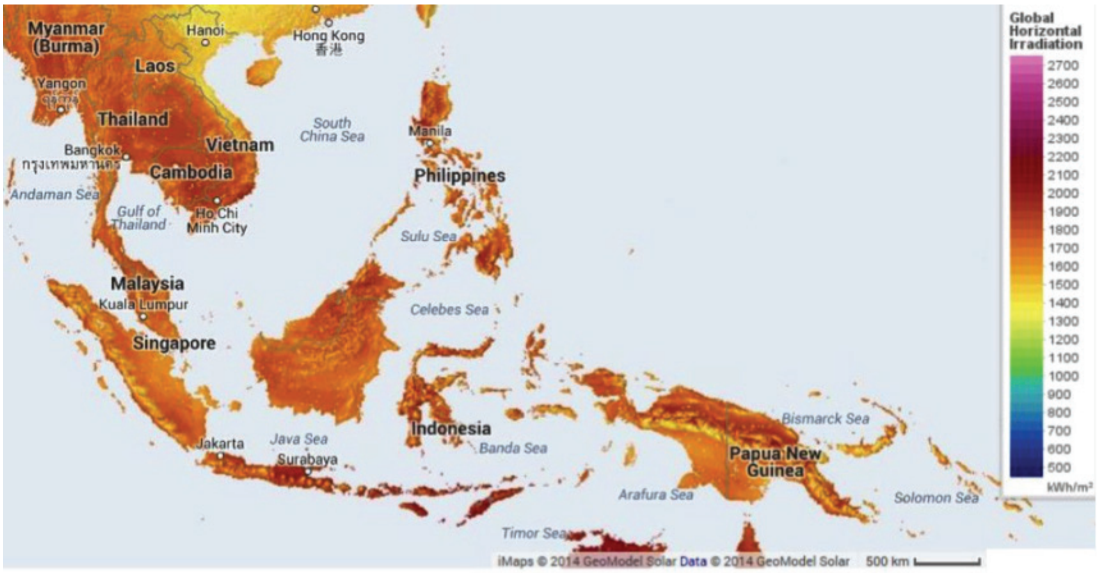
Rapid growth in renewable energy suggests that transition away from fossil fuels is under way. In 2014, global solar and wind annual installations set a record of 95 GW, almost half of all new generation worldwide. Established business models are now in question, after European utilities, mostly using coal and gas, lost $600 billion in value in the five years to 2014 [5]. Forecasts for power sector business growth suggest declining revenues and asset values for fossil fuel technologies (although current low international prices may moderate this trend somewhat) and growth opportunities for alternative generation.

While these dynamics clearly point to risk for Cambodia in continuing to invest in large-scale hydro and fossil fuel generation, there are also significant opportunities for accessing support for renewable generation uptake. Developed countries at COP21 reaffirmed their previous commitment to $100 billion per annum climate finance assistance to developing countries by 2020 as a baseline for possible increases post-2020. Development partners will likely make available increased technical assistance, grants and concessional loans to support diffusion of decarbonization technologies and practices. Capital will flow if policy and regulation are clear, simple and stable, putting in place a coherent framework for planning and investment.

Power sector market dynamics in Cambodia

Cambodia has very considerable potential for the uptake of distributed renewable generation. A recent ADB report [6]

FIGURE 3:
Regional solar irradiance profile



Source: Mott MacDonald presentation to Asia Solar Energy Forum, June 2015 found that very significant quantities of solar and biomass generation could be economically viable in Cambodia. It certainly has one of the best solar resources amongst ASEAN countries (Figure 3).

In Cambodia, large-scale hydro and coal-fired generation plants currently provide power for between 8 and 11 cents/kWh (taking into account transmission and distribution losses of 7-8% to get the electricity to Phnom Penh). Solar installations above 1MW (industrial facility scale) currently represent the most competitively priced alternative renewable energy technology as they can now provide electricity profitably for as low as 12 cents/kWh (or 10c per kWh if 20% grant funding is available) [7].

In addition to being close to par on price, solar (and other distributed technologies) also has benefits for electricity reliability which contribute to making renewable energy cost-effective compared with large hydro and coal-fired generation. Significant uptake of distributed generation would help meet daytime demand peaks (reducing the need for additional central generation and for consequent further investment in network upgrades) and boost supply during the hot/dry season when hydropower output is much lower.

Daytime distributed generation is also complementary with using existing large hydroelectric power less during the day and more for evening peaks. In addition, utility-scale solar generation does not involve a significant land footprint and can be constructed and put in operation more rapidly than hydropower or coal-fired generation. Cambodia could add 1,000 GWh to its generating output by constructing 700MW of utility scale solar on 1400 hectares of land. 1,000 GWh (additional to planned PDP generation), would mean the RGC's goal for achieving electricity self-sufficiency could be achieved in 2017.

Very large-scale central power generation involves significant external costs. Coal-fired power involves significant health impacts from particulate pollution and is highly carbon-intensive. In the US, the external costs have been estimated as being equivalent to an additional 18c/kWhr [8]. While nuclear generation at scale can appear cost-effective (if the potentially massive external costs of reactor breakdown are excluded) new safeguards to decrease further the likelihood of catastrophic events plus the full-costs of decommissioning will likely drive up costs (new nuclear in the UK is likely to be in the order of 13c per KWhr) [9]. Hydropower externalities are a matter for both national and regional consideration.

In Cambodia, solar installations above 1MW can now provide electricity profitably for as low as 12 cents/kWh.

Greater Mekong energy policy and development

Gains in electricity supply from hydropower projects must be considered against local and broader impacts. In addition to large dam reservoirs increasingly being assessed as involving significant greenhouse gas (methane) emissions, there are risks for fisheries, farming and food security in Cambodia and Vietnam because multiple upstream hydropower dams disturb flood cycles, nutrient flows, sediment transport and migratory fish breeding. A recent Mekong River Commission study found that 11 hydropower dams under development in the Mekong River basin would reduce fish biomass by around 50% if all were in operation [10]. Farmers and fishers downstream would face declining yields and incomes, putting at risk Mekong delta food exports worth $10 billion annually. Transboundary impacts such as these have already raised considerable tensions between GMS countries. It may be possible that large hydropower projects can generate net benefits but it is important for countries to carefully assess all costs and benefits, including transboundary impacts (and possible compensatory payments) and the effects of climate change over time (which will exacerbate impacts).

GMS countries have made enhanced power trading across the region a policy objective, as this is expected to drive considerable economic benefits from economies of scale and drawing on the comparative advantage of economies' differing resource profiles. The volume of large hydro and thermal power projects currently under development raises questions, however, of regional saturation: not all proposed projects will prove viable if GMS supply outstrips forecast regional grid demand (which may well be lower than expected due to improving energy efficiency and widescale uptake of distributed generation and storage). This adds a further layer of risk around large hydro and fossil fuel generation.

Thailand, Vietnam and Laos have adopted non-large hydro renewable energy technology targets, in part to hedge against risk. Cambodia should also consider scaling up RE investment to hedge against these risks, including by adopting RE targets.

Barriers to uptake of distributed renewable energy generation

Current RGC actions to bring forward completion of its national grid to 2018 mean there are opportunities for significantly scaling up ongrid distributed generation, particularly from rooftop solar. Also, around 820,000 (30%) of Cambodian households are currently not scheduled to have access to the grid until 2030 at the earliest. There is considerable scope

Cambodia should adopt (non-large hydropower) renewable energy targets, as Thailand and Vietnam have done.

for accelerating existing rollout of solar home systems (SHSs) to provide them with earlier, affordable electricity access.

Although uptake of distributed RE in Cambodia has to date been on a small scale, the lessons learned from the programs already implemented are valuable in considering the scope for scaling up RE going forward. Key constraints holding back RE investment include:

Lack of an RGC renewable energy/generation target: adoption of a target and a suite of policies to support their uptake is needed to give Cambodian and international private sector investors (as well as climate finance sources) confidence to invest at significant levels.

The ongrid RE regulatory environment is unclear: industry, commercial businesses and households have been deterred from investing by the lack of formal regulations around provision of distributed electricity to the grid. There has also been a lack of clarity in relation to utility scale solar generation where the rules for applying for tenders for additional supply under the power development plan are not widely understood.

Lack of fair value paid for excess generation sent to grid: an approach is needed that recognises the value of additional daytime electricity supplied close to the point of consumption. Initially, RGC could extend existing ad hoc net metering arrangements (customers are charged, over a billing period, for their consumption less any excess electricity sent out to the grid) to all distributed generation facilities. Net metering could then transition to 'fair value tariffs' (payment for electricity sent to grid at a rate to be determined, but likely between EDC's substation and retail rates). Such tariffs would require upgrading of metering facilities and capacity building in RGC power sector administration.

Access to finance: Cambodian banks have to date been cautious about investing in non-large hydro renewable energy: a revolving fund able to support concessional loans focused on distributed RE uptake, backed by development partner finance in partnership with the Cambodian banking sector, would help overcome up-front capital barriers.

Taxation issues: solar panels and equipment are still subject to VAT but suppliers are unable to pass on this charge to end-consumers, as is the case for most goods and services, given electricity purchases (usually from EDC) are VAT-exempt. Sustainable energy equipment generally does not attract import duties but a 7% duty still applies to solar equipment.

Developing a coherent vision for renewable energy uptake and putting in place a regulatory environment to support it will bolster energy security.

Support for uptake of distributed renewable energy generation

There is considerable international finance sector interest in looking for 'bankable' renewable energy projects in the Greater Mekong Subregion. As global emissions reduction ambition increases following COP21 in Paris there will likely be increasing incentives for developing countries, such as Cambodia, where energy infrastructure is still developing rapidly, to consider even more ambitious pathways towards very low carbon generation signatures in coming decades. Bilateral development partners and international funds, such as UNFCCC's Green Climate Fund, the multilateral development banks' Climate Investment Fund and the Global Environment Fund are all looking to leverage private sector investment to accelerate uptake of renewable energy. Projects will, however, be more readily considered 'bankable' where there is a clear policy and regulatory framework in place that will support uptake of renewable energy.

Development partners could support RGC to establish such an enabling environment by supporting the administration to address the key constraints identified above as well as supporting capacity building involving the following elements:

- education and training of MME, EAC and EDC staff in relation to managing:
  - a range of technologies, including RE, as part of electricity supply;
  - net metering and 'fair value' tariffs;
- upgrading existing grid management to include 'smart grid' monitoring/ management technologies;
- installation and maintenance standards to ensure performance and safety of RE equipment; and
- enhanced secondary and tertiary vocational training to address growing skills needs.

RGC officials have indicated on an informal basis that the RGC could consider looking to scale up RE, particularly solar, to 10% of 2015 peak demand capacity (around 100 megawatts) but have expressed concerns that Cambodia's power sector cannot accommodate significantly more than this level. Consistent with other developing countries having indicated ambitions for renewable energy uptake considerably higher than 10% of supply/ demand (eg India, Uruguay, Thailand), analysis and stakeholder discussions suggest RGC could readily achieve a target of around 150 MW using only rooftop solar for factories, offices and households, even before considering the potential contribution of biomass and other generation. If significant climate finance is available to support the capacity building package identified, then higher targets could be considered (see box).

To move towards a more diversified, more secure and more reliable power supply Cambodia should drive significantly enhanced RE uptake.

Potential targets for scaling up sustainable power generation

Officials have indicated informally that RGC could consider looking to scale up RE, particularly solar, to 10% of 2015 peak demand capacity (around 100 megawatts). A more ambitious target would be one representing 10% of RGC's anticipated peak demand in 2020 (1556 MW) – this would represent building from around 35 MW currently operating RE to 156 MW in 2020.

Cambodia could also, however, set a longer term target for 2025, of 10% of electricity supply (in gigawatt hours (GWh) sent out). On MME's current forecast for 2025 (12,000 GWh, Fig 1) that would represent 1,200 GWh, requiring 850MW solar generation capacity (if solar alone were used). In this case it would make sense for the 2020 target to be in the order of 350MW to come from RE. Pursuing such a target would enable RGC to defer plans for 220MW of the additional 530MW of coal-fired generation being considered for development by 2025. Pursuing a 20% target (2400 GWh), together with robust action on energy efficiency would mean there would be no need for additional coal-fired generation to 2025.

NEXT STEPS:
Key steps for RGC to consider

Developing a coherent vision for putting Cambodia on a low-carbon development path, as well as designing a policy/ regulatory environment to support such a transition will: bolster Cambodia's energy security and economic competitiveness; hedge against potential stranding of assets in a fluid technology cost environment; and enhance Cambodia's capacity to attract further climate finance. Some key potential steps towards these goals are set out below.

1. Adopt an interim renewable energy generation target for Cambodia, given contemporary pricing – pending establishing a target for 2025, based on detailed study of what would constitute a cost-effective but ambitious level of RE to integrate into the power mix. The study should take account of the external costs associated with large hydro and coal-fired electricity generation. Possible interim targets include:
    - 100MW before 2020 (representing 10% of peak demand in 2015 of around 1000MW)
    - 156MW in 2020 (representing 10% of peak demand in MME's low case (+20% reserve margin) forecast for 2020)
2. Clarify the regulatory environment regarding renewable energy for Cambodian and foreign investors, as well as development partners looking to leverage private sector investment flows.

- Formally recognise in law the right of onsite generation, notably rooftop solar, to supply electricity for own use and to supply excess electricity to the national or local grid.
    - > Establish, in 2017, appropriate 'fair value tariffs' (per kWh) for electricity sent out - following a detailed study of the value sustainable generation close to the point of consumption represents.
    - > Pending establishment of specific fair value tariff rates as above, a 'net metering' approach, similar to that proposed by the Solar Energy Association of Cambodia to MME in 2015, should apply (whereby usage over a billing period reflects consumption from the grid minus electricity sent out).

3. Develop a concept note to seek international development support to assess the scope for an incentive scheme that will help close the gap between the cost of non-large hydro renewable energy and other generation technologies and to establish a concessional loan rolling fund which could address initial capital barriers and support RE uptake.
4. Further develop a proposal for development assistance to assist RGC with implementing an enabling environment, involving:
    - education and training of RGC energy agency staff in relation to managing:
        - > a range of technologies, including RE, as part of electricity supply;
        - > net metering as a stepping stone to fair value tariffs;
    - upgrade of existing grid management technology to include appropriate RE 'smart grid' monitoring/management technologies;
    - installation standards to ensure performance and safety of RE equipment;
    - enhanced vocational training to address growing skills needs; and
    - consideration of fiscal instruments, such as a carbon tax, with revenue required to address the environmental impacts of fossil fuel generation.
5. Consider removing VAT and import duty from solar generation equipment, consistent with decisions to support sustainable energy by exempting sustainable biomass energy products from VAT, and also recognising that purchasers of solar equipment cannot pass on VAT costs as part of electricity prices.

Introduction

The Royal Government of Cambodia (RGC) has plans for growing the power generation sector and transmission/distribution significantly in the period to 2020, in order to achieve key national policy objectives for the power sector, including:

- improving energy security (reducing reliance on imported electricity);
- improving efficiency to enable lower prices for consumers (business and households);
- extending grid quality electricity to all villages by 2020 and 70% of households by 2030.

Recognising that economic growth and changing consumer patterns have been driving annual electricity demand growth in the order of 20% per annum, resulting in continued reliance on imported electricity from neighbouring countries and ongoing high electricity prices, RGC's current strategy to meet the above policy objectives primarily involves increasing power generation capacity very significantly, almost entirely from centralised large hydro and coal fired power plants. By 2020, under current planning, less than 1% of total electricity supply will come from distributed renewable energy sources.

There are a number of developments, internationally and in Cambodia, that can affect the cost-effectiveness of this planned increase in power generation. Electricity globally is undergoing a paradigm shift driven by two interrelated structural factors: first, the climate imperative is pushing decarbonization and transition to renewable energy, primarily solar and wind; and second, technological advances are pulling electricity systems in new directions, driving prices down and performance up for solar and storage. This paradigm shift is prompting concerns about misallocation of capital and stranded assets among a broad constituency of policymakers, investors and utilities.

The potential fiscal and economic consequences of overinvestment in large-scale centralised generation and network infrastructure pose relatively greater risks for developing and least developed countries as long term lock-in of expensive power generation and distribution infrastructure will proportionally have a greater impact. Least developed economies with relatively underdeveloped infrastructure also have opportunities, however, as they can 'leapfrog' investment in more traditional generation technologies to distributed technologies which can be more readily paced to match economic growth, with lower debt exposure.

In Cambodia, significant investment in the generation sector over the last decade has improved electricity supply reliability considerably but there are also potential downsides to the substantial increases in centralised generation: large scale hydropower projects' output has dropped more than expected during increasingly climate change-affected dry seasons, and additional coal-fired generation has direct detrimental air pollution and local ecosystem impacts, as well as adding to greenhouse gas emissions globally.

RGC may therefore wish to consider whether there is scope to diversify, in a cost-effective way, its planned power generation supply mix, to reduce direct and indirect environmental impacts

Least developed economies with relatively underdeveloped infrastructure also have opportunities, however, as they can 'leapfrog'.

from the power sector and to hedge investment risk through a greater proportion of distributed generation, rather than relying almost entirely on central generation.

RGC has already taken key steps to address potential risks to national development posed by climate change such as development of Cambodia's Climate Change Strategic Plan and the National Policy on Green Growth. The National Council for Sustainable Development (NCSD), which incorporates functions previously overseen by the National Councils for Climate Change and Green Growth, has responsibility for coordinating integrated whole-of-government strategies, including in relation to energy, to identify actions to advance sustainable development.

Mekong Strategic Partners (MSP) proposed to Cambodia's National Council of Sustainable Development (NCSD) in 2015 to undertake an independent policy appraisal to contribute to Royal Government of Cambodia (RGC) policy discussions regarding developing Cambodia's power supply mix to strengthen energy security, consistent with strong economic growth and environmental sustainability. Minister Say Samal, NCSD Chair, agreed to the study proceeding with a view to its going, as an information paper, to NCSD in early 2016.

The study aims to support RGC's deliberations on enhancing its power supply sector, consistent with key planning documents, including the Rectangular Strategy, the National Strategic Development Plan, the Cambodia Strategic Plan for Climate Change and the National Policy on Green Growth.

The terms of reference for the report are to conduct an independent analysis around:

1. costs/benefits, including sensitivity analysis, of Cambodia's planned electricity supply mix, taking into account:
    a. technology, climate finance and fuel cost trends, regional policy best practice, and supply/demand trends, based on recent experience of peer countries;
    b. transmission/distribution investment required;
    c. economic externalities, such as environmental/climate impacts;
2. the potential for cost-effective uptake of a broader range of technologies, taking into account different user needs at:
    a. industrial level;
    b. urban commercial and household level;
    c. rural household level (including the potential for new micro/mesogrids);
3. existing policy and practical impediments to increased uptake of renewable energy, notably solar, including through further investment by the private sector.

The report has been prepared over November 2015 to January 2016, based on:

- MSP independent research and analysis
- consultation with RGC relevant agencies (NCSD, the Ministry of Mines and Energy (MME), Ministry of Economy and Finance (MEF), the Electricity Authority of Cambodia (EAC), Electricite du Cambodge (EDC); and
- consultations with the Cambodian renewable energy industry, donor organizations, NGOs/CSOs and potential investors in the finance sector.

Hedge investment risk through a greater proportion of distributed generation, rather than relying almost entirely on central generation.

1: Cambodian power sector - 2015/16 context

Electricity consumption in Cambodia has been growing very rapidly: peak demand has nearly tripled since 2010 and the rate of increase is accelerating as national grid is rapidly developed and average incomes rise. While Cambodia's broad energy consumption is dominated by traditional use of biomass for cooking and heating, which represented some 70% of total consumption in 2014, this report focuses on the power sector: it is a crucial economic sector, with reliability and cost of electricity being critical both for conducting business and everyday activities and as a significant input to household and business costs. Surveys of business investment intentions regularly indicate the cost and reliability of electricity are barriers to scaled up investment in Cambodia. Certainly, improving the performance and cost-effectiveness of the power sector is a key priority for the Royal Government of Cambodia (RGC).

The Rectangular Strategy and the National Strategic Development Plan (RSIII and NSDP 2014 18, Cambodia's core policy documents) set out the top four priorities for the power development sector as being:

- further expanding … electricity production, especially from new and clean energy sources, along with … all levels of the transmission network (to) strengthen energy security and ensur(e) … reliable and affordable electricity supply and distribution (for development);
- further encouraging (private sector investment) … focusing on technical and economic efficiency and minimiz(ing) environmental and social impacts;
- (realizing) the goal "by 2020, all villages in the Kingdom of Cambodia will have access to electricity supplied by the national grid and other sources"; and
- further supporting the rural electrification fund (to) achiev(e) equitable electricity access for the population – through government budget, social fund from Electricity Du Cambodge (EDC) and (support) from other development partners [1].

The RGC also has a high level goal of at least 70% of all households having access to grid quality electricity by the year 2030. It is clear that security, access, reliability and affordability are critical drivers but a key priority for RGC is also the need to grow the sector in an environmentally sustainable way.

Cambodia's power sector involves one Government-owned provider, Electricite du Cambodge (EDC), dominating supply to households and businesses in Phnom Penh (60% of national electricity demand in 2015) [2] and other major cities, while a number of private sector Rural Electricity Enterprises (REEs), Provincial Electricity Companies (PECs) and Independent Power Producers (IPPs) provide service to peri-urban, rural and regional areas. IPPs also own and operate a range of generation facilities which provide electricity to EDC under various power purchase agreements (PPAs).

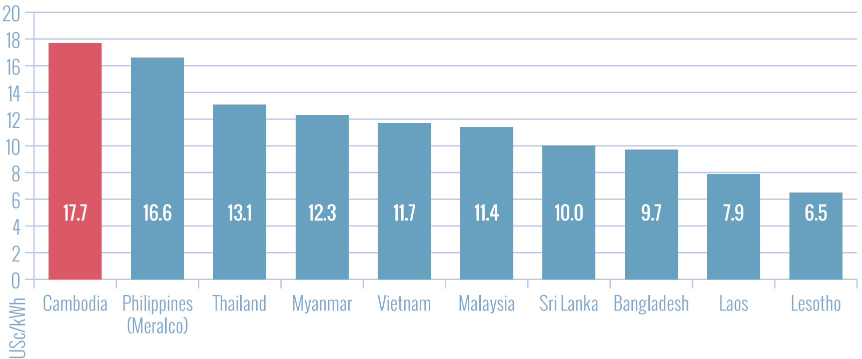
A key priority for RGC is also the need to grow the sector in an environmentally sustainable way.

Over the last five years, Cambodia's power sector has been transforming rapidly, making progress towards RGC's overarching electricity access targets. By mid-2015, 62% of villages were connected (and 56% of households) [3], compared with only 29% in 2010 [4]. Prices faced by grid-connected households and businesses remain high compared with other ASEANs (see Figure 1 showing prices faced by business) – despite EDC and REEs having been able to reduce prices somewhat in recent years.

For large numbers of villages previously not connected to the national grid electricity has often been provided by small REEs operating minigrids supplied by diesel generator sets. Such gensets are highly polluting and very costly, although low international oil prices in 2015 have eased price pressures. Current pricing in some rural areas remains above $0.25 per kWh. [5] although it is the RGC's intention to introduce a uniform national grid price of 800 riel ($0.20) from April 2016. This uniform price will, however, involve subsidizing a number of REEs as they continue to use expensive highly polluting diesel generation. Lower prices will likely mean increased electricity consumption and therefore increased greenhouse gas emissions and local health and ecological impacts.

More remote communities and households which cannot afford to connect to the grid only have access to even more expensive and even more pollution-intensive electricity. Families and businesses use car batteries to run lights and TVs, regularly taking the batteries to battery charging stations (BCSs) where they are topped up from diesel gensets. Battery life, after frequent recharging, is usually around 6-12 months and the effective electricity cost for small businesses and households is well above $1/kWh.

FIGURE 1:
Regional electricity prices for large industry customers [6]



Source: ECA calculations using data from national electricity regulatory and utilities. The tariff for Cambodia is that applicable for 2015 for MV customers located in Phnom Penh and Kandal. The tariff for the Philippines is that applicable for customers served by Meralco using the February 2015 generation charge.

RGC's Power Development Plan 2005-24 (PDP)

Cambodia's PDP is focused on boosting generation capacity and extending network to achieve the RGC's overarching electricity goals. Very significant private sector investment under the PDP (mainly Chinese hydropower companies) has driven a rapid increase in domestic generation capacity (from 308MW in 2009 [7] to 1584MW at end-2014) – substantially from large hydropower plants in the Koh Kong and Kampot provinces and, more recently, from coal-fired power plants in Sihanoukville province, in addition to a potential 200MW coal-fired power plant in Oddar Meanchey. While increasingly severe dry seasons have meant lower than anticipated hydropower output the significant increase in domestic capacity has considerably decreased the frequency of power interruptions in Phnom Penh.

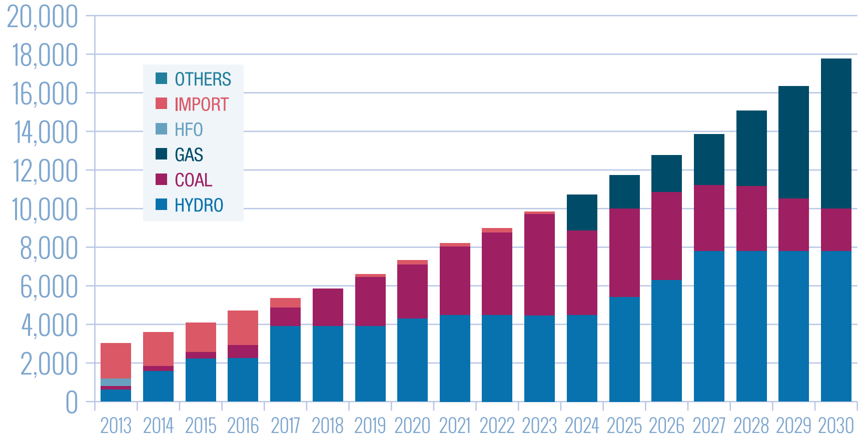
RGC planning for further investment in generation capacity is also focused on large hydropower and coal-fired plants (to 2023) and ultimately significant quantities of gas-fired generation – as Cambodia plans to have developed its offshore oil/gas resources by 2024 (see Figure 2).

In 2015 and 2016 imported electricity, mainly from Vietnam and Thailand, is expected to be similar, in absolute terms, to levels in recent years. Imports, however, now represent a declining proportion of Cambodia's supply – due to the rapid ramp-up of domestic generation. From 2018, MME expects imports to make up only a very small part of supply. It is notable, however, that Cambodia's PDP does not currently factor in a major contribution from distributed renewable electricity: all major additional capacity is central large-scale generation, which entails risks of assets becoming devalued over the medium term as RE and storage become increasingly competitive.

MME's forecast to 2030 – see Figure 2 – indicates the RGC's expectation that Cambodia can rely heavily in the 2020s on economic development of its own gasfields (although current prices do not provide a strong investment signal). The graph also indicates an expectation that gas will crowd out coal fire generation from 2023, which raises questions regarding the longevity of the coal fire plants which are currently being considered.

In addition, RGC, until very recently, had flagged very significant investment to 2020 in large hydropower (as set out in Table 1 below) but the extent of hydropower generation signaled in Figure 2 is only consistent with the completion of the Lower Sesan dams to 2020.

FIGURE 2:
RGC forecast to 2030 for electricity supply (in GWhrs) by technology source



Source: MME, September, 2015

TABLE 1:
RGC outline of potential large hydropower investment to 2020

Hydropower Project	Installed Capacity (MW)	Expected Year Operation
Lower Se San II	400	2016
Stung Cheay Areng	108	2017
Lower Se San I	90	2018
Sambor	2600	2019
Stung Treng	900	2020

Source: MME, Enrich Forum, September 2015

The RGC has in fact confirmed, in January 2016, that it will not look to develop any new hydropower dams prior to 2020 [8]. Figure 2, however, indicates that additional large hydropower is still considered likely to contribute significantly post-2020.

There could still be significant shortfalls for several months of the year, however, as hydropower only performs at around 25% rated capacity over the dry season [9]. To meet any shortfalls, RGC is considering adding a further 530 MW of coal-fired power to the existing 270 MW in Sihanoukville, [10] which is consistent with the power supply envisaged in figure 2 until 2023. It is not clear why coal output declines from 2023 to 2030 but increasing gas generation from 2023 is consistent with RGC ambitions to develop its offshore gas fields.

RGC is looking to grow its generation capacity rapidly to 2030, taking advantage of its hydro and offshore gas resources, to become self-sufficient if possible and then export electricity to its ASEAN neighbours. RGC actively participates in ASEAN discussions to boost network infrastructure investment to facilitate power trading.

If growth in domestic generation capacity in hydro and coal proceeds at the pace planned, there may not be sufficient generation to meet demand by 2020. Forecast domestic generation for 2020 is around 7800 GWh (Figure 2) and EDC figures show sales of electricity (in GWh) have grown, on average, at 19.8% per annum over the 5 years since 2010 [11]. Even if demand moderates to 16.5% around 9,000 GWh would still be needed in 2020 and Cambodia would need to supply an additional 1000 GWh (although action to improve the economy's energy efficiency could reduce the shortfall) [12]. RGC could, however, prepare to meet any shortfall by taking advantage of falling prices to diversify its power mix through scaled up RE – rather than continuing to import electricity on a large scale or bringing forward potential large-scale hydro and coal-fired generation.

Extent of variable renewable energy uptake

As noted above, Cambodia's PDP currently does not envisage a major role for non-large hydropower RE over the next decade, even though solar generation achieves maximum output during the dry season and biomass generation also has the potential to offset low hydropower output in dry season.

In addition to programs supporting offgrid uptake (see below) through solar home systems (SHS, up to 1.5 MW in total) and household and commercial piggery biodigesters (up to 1.5 MW) there has been some investment, supported by a range of development partners, in trialing distributed on-grid RE generation to support industry and the commercial sector over the last 5 years: sugar cane bagasse biomass gasification plants (around 25 MW); small-to-medium-sized solar PV installations (up to 3 MW); biomass gasification in the rice-milling industry (around 0.2 MW); 2 micro-hydropower plants (0.4MW); and some modest investment in jatropha (biofuel) and cassava (ethanol) plantations [13]. There has also been an attempted windpower installation at Sihanoukville port which has experienced mechanical problems and is currently not generating. These investments total less than 35 MW, compared with construction to date of over 1200MW of large-scale hydro and coal power generation under the PDP.

Electricity Access

As noted above, RGC has also begun to make rapid progress in extending electricity grid throughout Cambodia under its Rural Electrification Master Plan.

Whereas only Phnom Penh had any grid to speak of in 2005, major transmission lines were subsequently constructed connecting Siem Reap and Battambang to Thailand's network and Southeastern Cambodia to Vietnam's network, allowing import of substantial quantities of electricity (in addition to smaller scale imports from Laos). These, and other expansions of transmission and distribution grid, have involved significant concessional finance from international development partners (eg WB, ADB, JICA, KOICA, KFW, AFD, DFAT) as well as Cambodian private and public sector investment.

In mid-2015, 62% of Cambodia's villages, in 18 provinces, have been connected to the national grid. EDC now expects the national grid to reach the remaining 6 provinces (Kratie, Stung Treng, Rattanakiri, Mondulkiri, Kampong Thom, Preah Vihear) and almost all remaining villages by 2018 [14].

Even once all villages are connected, current RGC policy is that some 820,000 households (30% of 2013 households) [15] will not be grid-connected before 2030, at the earliest. RGC policy also indicates RE can provide electricity for many currently relying on BCSs. EDC's Rural Electrification Fund (REF), initiated by the World Bank (and currently supported by KfW), has rolled out 20,000 sub 100 watts SHSs (representing around 1.5 MW in total) and is aiming to achieve around 20,000 more by 2018. In parallel, the Good Solar initiative (funded by EU/AFD) aims to roll out 25,000 quality 120W SHSs by 2018 – representing around 1.9 MW. Providing access to even half of the 820,000 households currently scheduled to remain offgrid will require much more significant rollout of SHSs.

It is clear that RGC has been making substantial progress towards achieving a number of its objectives for the power sector. This report investigates the potential for Cambodia to continue to advance towards achieving the objectives of secure, affordable and reliable electricity for Cambodian villages and households while diversifying its power supply mix, for greater energy security and sustainability benefits, given changing technology cost relativities.
To date investment emphasis has been given to largescale hydropower and coal but central generation models are facing challenges internationally from distributed RE and storage technologies. The RGC has indicated investing in new and clean energy technologies is a priority and technology cost developments mean scaled up RE investment is increasingly affordable for Cambodia. The next section investigates some of these developments.

2: Global energy transition: dynamics and opportunities

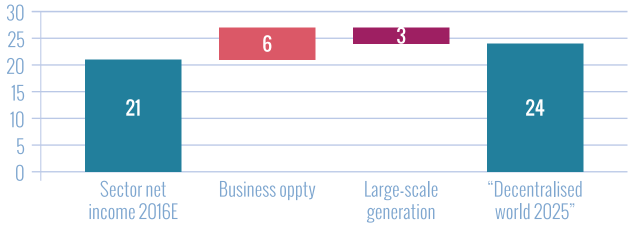
In December 2015, Germany's RWE, one of Europe's biggest utilities, announced it was turning from fossil fuels to renewable energy [16]. A year earlier E.ON, RWE's rival, committed to renewable energy and energy services as its primary business, with fossil fuel assets spun off into a separate company [17]. In the United States, NRG, one of the world's largest utilities, took similar steps to E.ON [18]. Net revenues for European utilities could rise 15 per cent as distributed solar and storage plus smart grids replace obsolete large power plants, especially fossil fuel assets, in the years to 2025 (figure 3) [19].

Such forecasts for power sector prospects over the next decade suggest growth opportunities for alternative generation and declining revenues and asset values for fossil fuel technologies. Current low international prices, if they continue for a number of years, may moderate this trend somewhat but the general direction is clear: relatively young technologies are improving in efficiency and cost-effectiveness, at the expense of mature technologies which have less scope to identify new cost-cutting measures.

Industry initiatives such as the RE100 [20], which includes Elion, Infosys, P&G and UBS, are gathering pace. Others, such as Apple and Google, are pursuing unilateral endeavours [21]. Their needs are substantial: Google, for instance, recently added 800 MW of wind and solar PPAs bringing its worldwide portfolio to 2.8 GW [22], enough to power Cambodia. A survey revealed corporate contracting for renewable energy, particularly non-industrials and increasingly smaller firms, is expected to accelerate into 2017 building on rapid growth since 2013 [23].

Concurrently, residential solar is blossoming in developed economies and increasingly in developing economies. Community governments are also regulating and investing to develop solar and wind [24]. Consequently, the role for large conventional power plants will shrink in the coming decade (see Figure 3) [25].

FIGURE 3:
Solar €3 billion net income opportunity for European utilities



Source: Will solar, batteries and electric cars re-shape the electricity system? UBS, 2014. [19]

Utilities, consumers and investors in developed and developing countries are switching to renewable energy not only to constrain environmental impacts and reduce the regulatory risk of emissions limits and carbon pricing but also because it is increasingly economic in its own right. Obtaining finance may also become harder for generation businesses with large fossil fuel portfolios due to growing concerns among investors and lenders [26], implying higher costs while renewable energy costs are falling. Google considers that renewable energy now makes "business sense" [22].

Costs and Competitiveness

Increasing scale is a driver of remarkable declines in cost. In 2014, solar and wind annual installations set a record of 95 GW, almost half of all new generation worldwide, involving $270 billion investment [27].

Globally, the installation cost of wind and solar (averaged) fell 28% from 2011 to 2014. In many countries onshore wind, excluding subsidies and carbon prices, is cheaper than coal and gas while solar is closing the gap (Table 2) [28].

Rooftop solar costs have also fallen at steady rates due to a combination of falling costs of solar modules and other equipment, such as inverters, plus increasing installer experience, cheaper finance, and reductions in soft costs, for example permitting (Figure 4) [29]. Solar rooftop deployment has accelerated, especially in markets with good solar resources or where term-limited subsidies are granted by governments to accelerate diffusion [30].

Costs are expected to continue falling due to increasing returns to scale, more efficient designs, and advances in materials and manufacturing. Within a decade unsubsidized solar and wind in India are projected to cost less than coal and gas even without carbon pricing (Figure 5). In China, gas is already uncompetitive against wind and some solar, and coal will be in the same position by 2030.

Energy Transition

Rapid growth in renewable energy suggests that the transition away from fossil fuels is under way. Energy transitions are rare events with profound consequences for the economy and society (see Appendix 1). Driving the energy transition are powerful trends in technological innovation and global policy to tackle

TABLE 2: Wind and solar costs - end-2015

Utility solar (global)	Wind 100 MW (China)	Overnight solar (Chile)	Wind (Chile)
6-8 ¢/kWh	4.5 ¢/kWh	9.7 ¢/kWh	7.8-9.5 ¢/kWh
[31]	[32]	[33]	

FIGURE 4:
Rooftop solar costs [29]

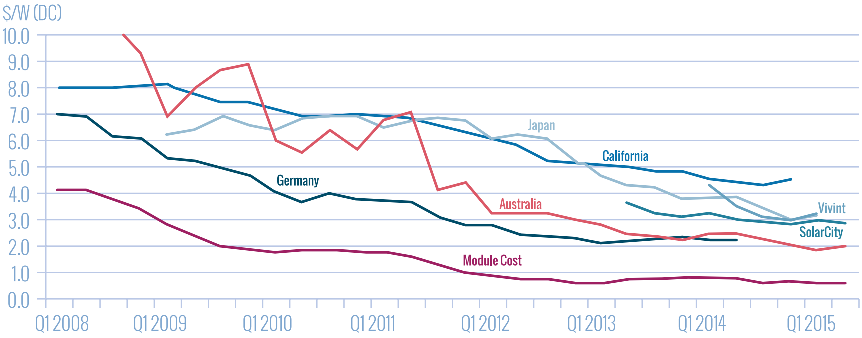
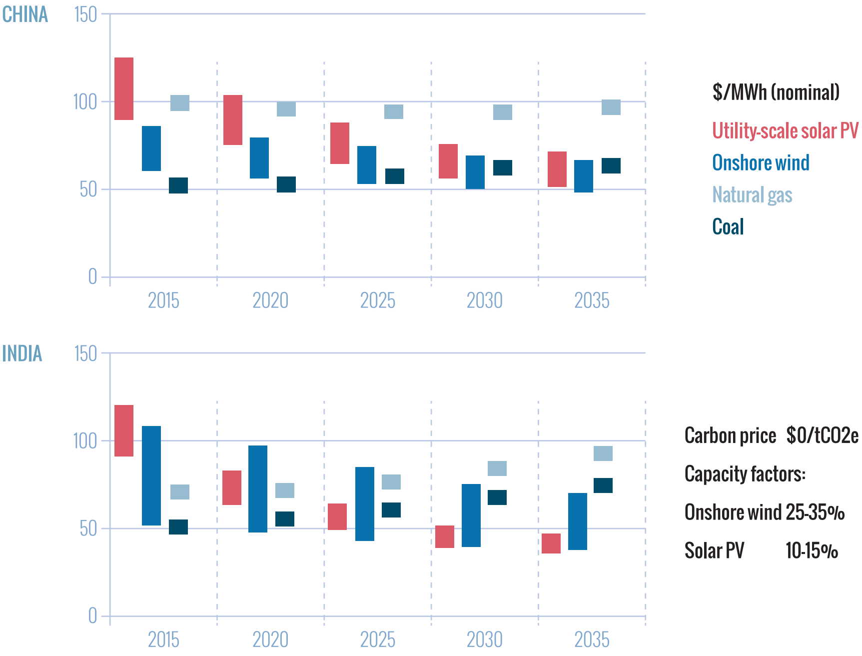


FIGURE 5:
Levelized cost of electricity 2015-2035 [34]

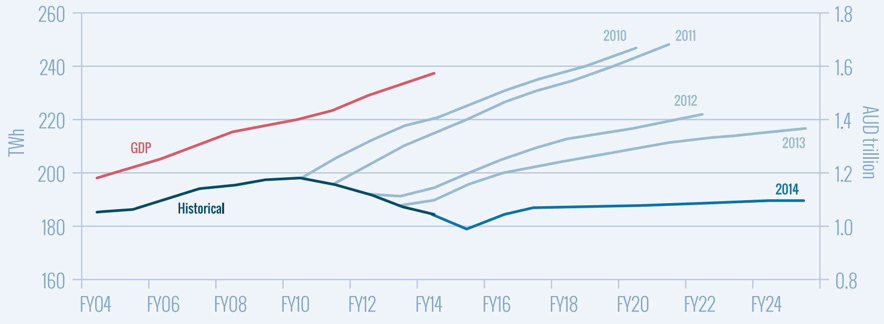


climate change, itself largely caused by consumption of fossil fuels. Historically, energy transitions, from wood to coal, coal to oil, oil to gas, have taken 50-100 years but the transition to renewable energy is looking like being much faster. Meanwhile, the effects are already beginning to transform the structure and economics of electricity supply as events in Australia demonstrate (see box below). Long-held assumptions and established business models are now in question, challenging investors and regulators to reconsider plans and projects to ensure they will remain viable as clean energy expands.

Market restructuring: the case of Australia

Falling costs have already encouraged rapid adoption of renewable energy by consumers and investors in Australia. In a decade solar and wind rose from almost zero to almost equal large hydro output in 2014, equivalent to almost one in five household rooftops having solar panels [35]. Although the global financial crisis played a role in recent very significant reductions in national grid demand (see Figure 6) the rapid uptake of rooftop solar contributed the major part [36] [35]. Parallel to falling demand household electricity bills rose 85 per cent from 2006 to 2013 – mainly to cover overinvestment in grid upgrades which implicitly were based on consumers not embracing rooftop solar. Rising bills prompting further demand reductions will drive write-downs for utilities' asset values [37] despite attempts to introduce fees on solar, storage and electric vehicles to prop up revenue [38] [39]. Whether future demand from electrification of transportation and heat will be sufficient to repay grid expansion costs and preserve utilities' market values remains to be seen. Further structural change may follow by 2020 if battery storage for consumers meets industry cost expectations [40] [41]. Australia's experience is likely to be repeated in other countries as costs for solar and storage continue to decline, particularly where central electricity tariffs are being increased to recover costs from a declining customer base [38].

FIGURE 6:
Australia electricity demand projections [34]



The transition is also supported by increasing evidence of the true costs of fossil fuels for public health, primarily due to air pollution, which is a leading cause of mortality especially in developing countries such as China [42] [43]. The International Monetary Fund (IMF) estimated coal caused damage costing $3.4 trillion in 2014 (equivalent to up to 16 per cent of Asian developing countries' GDP) [44]. Electricity prices in the United States would at least double if they reflected damage caused by burning coal [45].

International Policy for Renewable Energy Diffusion

The dynamics will almost certainly intensify as costs fall and awareness of the benefits grows. The Global Commission on the Economy and Climate (GCEC) has quantitatively assessed that benefits will outweigh costs in a world powered by clean energy [46]. Maximizing net benefits depends on the pace of energy transition which will be strongly influenced, in this early phase, by national and international policy and thereafter by RE's increasing cost-competitiveness.

Deployment is certainly being accelerated by current public policy action worldwide to decarbonize energy. China may withdraw fossil-fuel subsidies [47] and may stop developing coal power plants by 2020 [48] as it develops 150 GW of solar and 250 GW of wind [49]. That year solar should generate one-third of electricity in Morocco. In Uruguay, solar, wind, hydro and biomass already generate 95 per cent of electricity [50].

By 2030 coal will generate far less electricity than today, if any, in Germany [51], the United Kingdom [52] and the United States [53]. By 2030 renewables should supply half of California's electricity [54] and Sri Lanka will be fossil-fuel free [55]. Regulatory reform is also already under way in California, Germany, Hawaii, New York and the United Kingdom to stimulate further investment in energy efficiency, demand-side management and batteries.

Broadly speaking, the international community is pursuing decarbonization on two tracks to keep global warming well under 2 degrees Celsius:

1. Accelerated diffusion of energy efficiency and renewable energy technologies and best practices, particularly in developing countries where uptake may be limited by upfront cost and limited technical capabilities.
2. Market reform to internalize all costs into prices of energy to promote rational use and investment by the public and private sectors.

Market reform is being undertaken by sub-national, national, regional and global agencies and institutions with varying degrees of coordination and success but the primary approaches are internalizing external costs by either taxing carbon or establishing cap-and-trade mechanisms. Post-COP21 there is renewed interest in establishing international carbon trading regimes, and possibly border adjustments (via national import tariffs) on goods and services coming from carbon-intensive economies.

Developed countries at COP21 also reaffirmed their previous commitment to providing $100 billion per annum to support developing countries to pursue

The dynamics will almost certainly intensify as costs fall and awareness of the benefits grows.

low carbon development pathways (and this level may be increased). Development partners will likely make available increased technical assistance, grants and concessionary loans to support diffusion of decarbonization technologies and practices. It will be important, however, for regulatory conditions in recipient countries to be transparent and, without compromising governance, to expedite program implementation.

Overall, the trend in international policy is towards more cooperation and coordination, increasing ambition, and increasingly transparent regulation. In the next decade, resources to support RE uptake are expected to increase as regulatory conditions improve. Diffusion will, however, increasingly be driven by price competitiveness, access to finance and entrepreneurial drive. Competitiveness of solar and wind is expected to continue improving as learning rates continue to drive down costs and market reform proceeds.

Risks and opportunities for developing countries

What does the energy transition mean for policy and investment in countries like Cambodia? The short answer is that risks and uncertainties facing plans and projects increase if conventional approaches continue to dominate. Risk and uncertainty are manageable if policy and investment recognize and embrace technological change and market reform smoothly incorporates externality costs to improve the quality of price signals and increase efficiency. For Cambodia, an opportunity exists to reduce risks through early action. Conversely, pursuing conventional business models almost exclusively, with the potential for significant asset writedowns by 2030, would likely be more costly over that timeframe than investing in more significant levels of renewable energy to diversify the power sector mix.

Risks

Costs, competitiveness, and consumer defection: costs for existing and new fossil fuel or large hydro projects will at best remain constant but in many cases are likely to rise, particularly as the effects of climate change will likely mean, over time, decreasing output due to reduced water availability. A project initiated today has to be competitive against solar and wind when it comes online in 5-10 years and must remain so for at least 7 years thereafter to repay capital costs. High-carbon infrastructure may turn a loss, however, as the International Energy Agency has recognized [56]. Even thermal and hydro projects with long-term contracts may not be sound because as losses grow for public or private buyers the pressure to exit such contracts will grow. In addition, fossil fuel price volatility is an ever-present risk to competitiveness and output is at risk from intensifying climate change affecting water supplies [57] [58] [59] [60]. Low 2016 prices may mean major increases once the global economy returns to strong growth. With prices at current levels upside risk seems to be more prominent than downside price risks.

Fossil fuel and large hydro-electricity also face increasing competition in the retail market at the socket. Power generated by consumers, using rooftop solar, drives two interacting effects – as seen in the EU, Australia and California:

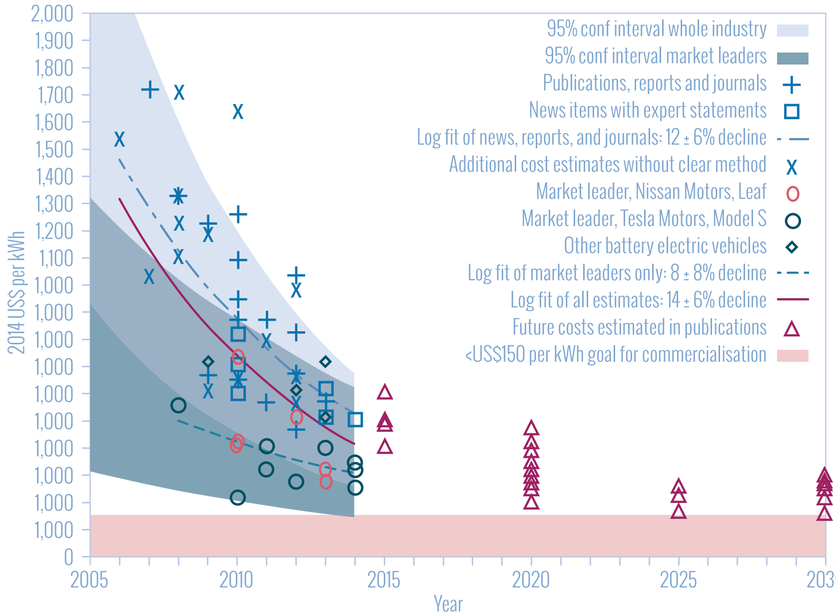
> **Risk and uncertainty are manageable if policy and investment recognize and embrace technological change and market reform smoothly incorporates externality costs to improve the quality of price signals and increase efficiency.**

1. Consumer demand for relatively expensive grid-provided central generation declines.
2. The consumer revenue base therefore shrinks for central generation providers, causing their -electricity supply prices to rise (which pushes even more consumers to seek out lower cost distributed alternatives).

The rising cost of central electricity tariffs and the falling costs of consumer solar and storage (Figure 7), raise the prospect of consumers disconnecting entirely from the grid [38][61] or drawing on the grid partially, for backup [62]. Whether consumers opt for independence or limited use of central electricity supply depends on individual circumstances and market characteristics. As costs fall, incomes rise, and alternative power sources multiply it may only be a matter of time before Cambodian households become power producers, either operating independently or trading electricity from their solar rooftops with local or regional markets. In these circumstances, developing country governments must weigh up the benefits of anticipating structural changes and managing disruption against staying primarily with conventional technologies, which may lead to stranded investments.

Prospects for higher cost central assets with long payback periods, such as fossil-fuel power plants and large hydro, may improve if significant demand from electrification of transportation and heat emerges sooner than anticipated and distributed RE cannot keep pace with those emerging demand sources. Expanding electrification may, at least for a time, ensure a place in the energy mix for legacy assets.

FIGURE 7:
Storage (EV Lithium-Ion) - rapidly falling prices [63]



Source: Nykvist & Nilsson (2015)

<u>Prices, efficiency and market reform:</u> pressure may also grow to reform fossil fuel prices to approximate their true costs for human health and climate stability [42] [44] [45]. Improving the accuracy of prices, by for example carbon pricing, would improve the efficiency and results of markets, leading to better decisions that should be beneficial for energy security, health and the environment. If external costs are incorporated into prices, fossil fuels become uncompetitive in the energy mix of almost all markets.

Conventional electricity assets and utilities, particularly those employing fossil fuel, are increasingly at risk of becoming stranded investments, generating heavy losses. The scope for such effects across the electricity and fossil fuel sectors globally is considerable, running into trillions of dollars [64] [65] [66]. If such large sums seem implausible it should be noted that European utilities, mostly using coal and gas, lost $600 billion in value in the five years to 2014 raising questions for the fiduciary duties of money managers [67] [68].

Energy transition is certainly not without risk where consumer prices are set by markets. Moreover, further technological development will doubtless affect market dynamics in unpredictable ways. For example, the rapidly falling cost of energy storage, including in electric vehicles, is one example of an emerging technology which will both make RE more functional and competitive but could also extend the viability of grid-based central generation (due to increasing overall electricity demand as electric vehicles displace fossil-fuel powered vehicles). Electric buses are already competitive and cars will be by the early 2020s, even with low oil prices. China switched to electric motorcycles over a decade ago (and the capital cost is similar to a four-stroke motorcycles common throughout Cambodia).

Opportunities

Technology, systems and principles to leapfrog to clean energy are available [69]. Systematic deployment in Cambodia requires long-term planning plus capital and capabilities. Capital will flow if policy and regulation are clear, simple and stable, putting in place a coherent framework for planning and investment. Capabilities can be nurtured with local and international resources and collaboration.

While climate finance available from public sources is increasing rapidly it will pale in comparison to funds available from private sources. That is essential because bilateral and multilateral funds are insufficient to meet global climate finance needs. Attracting private climate finance, whether via bond markets or direct investments, depends on the quality of the business environment. In some cases, even a few relatively simply changes to laws and regulation may be sufficient to improve bankability and unlock a much greater flow of funds.

Grants and concessional finance supporting early energy transition will be important to encourage developing countries onto low-carbon pathways and avoid the risks of high-cost carbon lock-in. Grants and loans to accelerate deployment of energy efficiency and renewable energy technologies are offered by bilateral and multilateral agencies.

The flagship Green Climate Fund (GCF) is expected to disburse much of the $100 billion developed countries previously committed to provide from 2020 (and the outcomes of COP21 suggest that this figure will increase post-2020). GCF is now actively looking to disburse funds through a first round in 2016. Direct investment in solar and wind power plants will need to demonstrate significant private sector co-investment/leverage as technical risk is low and private finance is beginning to become available at quantity. To take one recent example, Goldman Sachs announced in November 2015 it would invest $150 billion in clean energy by 2025 [70]. There is a significant opportunity for Cambodia as international private sector investors are actively looking for renewable energy projects in the GMS region, if the local regulatory framework is supportive of renewable energy uptake [71].

While climate finance available from public sources is increasing rapidly it will pale in comparison to funds available from private sources.

Institutional public climate funds could target support for policy formulation, including capacity building, to improve the business environment for private investment in renewable energy. Support could be extended to pilot projects to demonstrate replication and upscaling potential to policymakers and communities, while building confidence and tempering risk for private-sector investors. Another challenge that may not be solved fast enough without public funds include energy efficiency, still a difficult investment for private investors due to scale, complexity and split incentives. Already, the UNFCCC and the Global Environment Facility (GEF) have established initiatives in this area as energy efficiency improvements could reduce transition costs at least $2.8 trillion by 2030 [72] and create many jobs [73].

The rapid pace of RE adoption across developed and developing countries indicates that many already recognize that as far as commencing the transition away from conventional power sector approaches goes, the balance is shifting towards opportunities outweighing risks. Developing a coherent vision for putting Cambodia on a low-carbon development path, as well as designing a policy/regulatory environment to support such a transition should: bolster Cambodia's energy security and economic competitiveness; hedge against potential stranding of assets in a fluid technology cost environment; and enhance Cambodia's capacity to attract further climate finance. The next section assesses the comparative benefits and costs of various power generation technologies currently being used or considered for the Cambodian power sector, in light of Cambodia's RE resource profile.

3: Power sector market dynamics in Cambodia

Section 2 outlined significant increases in the competitiveness of renewable generation technologies and its impact on conventional power sector business models in developed and developing countries. This section explores whether Cambodia's renewable energy resources mean it is well placed to take advantage of falling RE prices to develop a more diverse power generation profile – hedging against the risk of stranded fossil fuel assets in the coming decade or so.

Cambodia's renewable generation resource potential

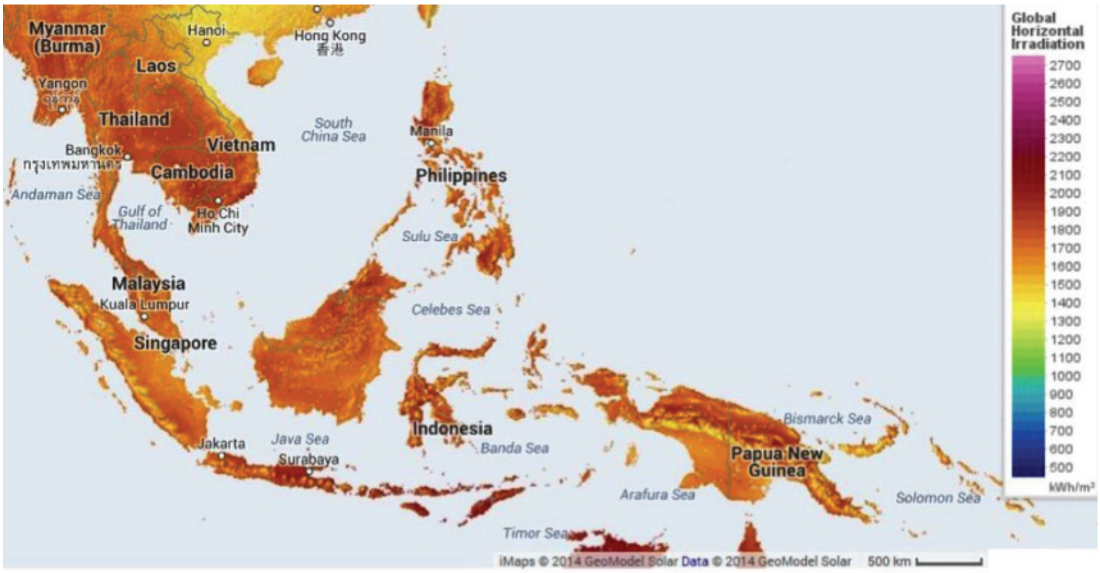
Cambodia has very significant potential for the uptake of distributed renewable generation.

In particular, its solar resource (averaging 5 kWhs/m2/day) represents one of the better insolation profiles in South East Asia (see Figure 8 below).

A 2015 ADB report on renewable energy potential in the Greater Mekong Subregion (GMS) estimated that Cambodia [74] has a high degree of solar irradiation and has a 'technical potential' for 8,100 megawatts of peak generation, potentially yielding nearly 12,000 GWh per annum, substantially more than previous estimates [75]. The study also considered that nearly 90% of the technical potential would be economically cost-effective in Cambodia, given ongoing high electricity prices. The solar resource is also positively correlated with the geographic distribution of Cambodia's population (see Figure 9 overleaf).

The ADB study also concluded that while there were good wind resource in parts of the country, Cambodia's higher speed (6-7m/sec) wind resources are not co-located with grid configuration. Finally the study found that there was

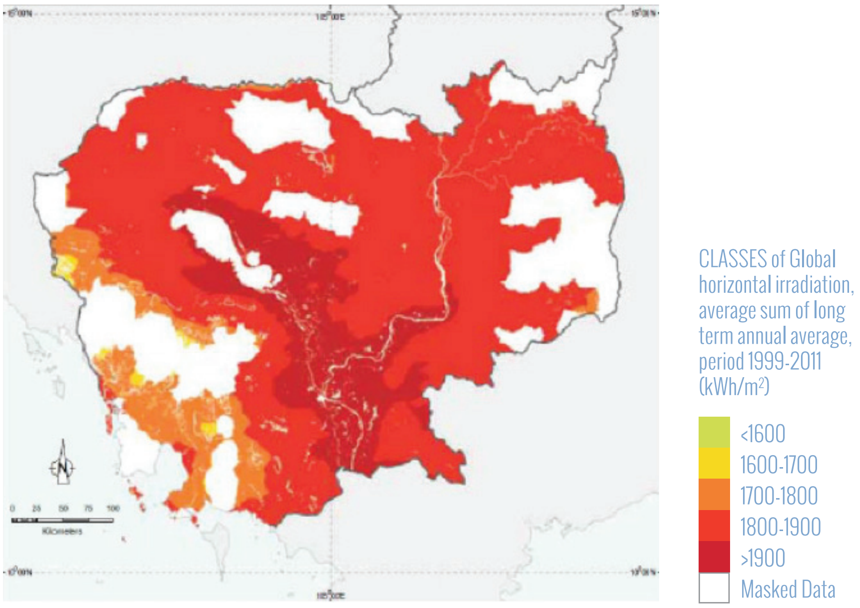
FIGURE 8:
Regional solar irradiance profile



Source: Mott MacDonald presentation to Asia Solar Energy Forum, June 2015 also significant potential for biomass generation (theoretically up to 15,000 GWh per annum) but the technical 'realisable' potential would depend on a number of local factors, notably specific residue to product ratios, surplus availability and waste calorific content [76].

Taking into account that cost relativities have shifted further (eg solar has become even less expensive) than when the research for the ADB study was conducted, it makes sense for Cambodia to investigate creating an enabling environment to support investment in renewable generation, notably solar. It may also be appropriate to reassess Cambodia's potential to use wind energy, given that new turbine technologies are now considered to be able to generate economically at speeds below 5 metres/sec.

FIGURE 9:
Areas potentially suitable for solar PV development



Source: GeoModel Solar; Lahmeyer International [78]

Costs and benefits of key power generation technologies

In order to form judgements about whether diversifying the power supply mix can enhance Cambodia's energy security it is important to consider the broad comparative costs and benefits of key technologies used in Cambodian power generation: both those currently being widely used in Cambodia (hydro, coal, liquid fuels) as well as modern technologies more recently adopted (solar, biomass). As the RGC has recently signed an MOU with Rosatom, Russia's agency responsible for managing its nuclear energy industry, to cooperate on nuclear energy research, this technology also needs to be considered [77].

In comparing different power generation technologies it is important to consider direct costs of both generation and transmission/distribution as well as indirect costs (externalities) including environmental, health and social impacts. Table 3 (overleaf) sets out the current range of international prices for new bid utility scale conventional generation and levelised costs for renewable generation in Cambodia, above 1MW [79], as well as externalities and other sensitivities that can affect competitiveness.

A decade ago, when Cambodia was setting the broad directions of its Power Development Plan (PDP, 2005 24), the costs of renewable generation technologies were much greater and short-term cost-effectiveness drove Cambodia's decision, as a least developed country, to opt for the scale efficiencies of large hydropower and coal-fired generation. Development partners supported renewable generation at the margins but the economic case for largescale uptake of renewables was not strong at that time. It is clear from table 3 that the picture has greatly changed in 2015. The cost of renewable generation is closing the gap with conventional technologies' costs. In Cambodia, solar PV, involving minimal environmental impact, is now almost as cost-effective as coal fired generation even without factoring in externalities confronting investment in coal technologies.

It is likely that the cost of solar generation will fall further as it is a relatively young technology: current energy conversion efficiency runs around 15% for solar panels but research models are demonstrating over 23%, which should drive significant further price falls [80]. Already, in Chile's October 2015 electricity auction solar technologies won long term generation contracts, offering electricity at scale at 6.3 cents per kWh (and 9.7 cents for night-time supply, involving storage) [81]. Cambodia's solar prices have not yet fallen to the same extent but if solar uptake scales up significantly further cost falls can be expected from the current price of around 12 cents/kWh for large scale installations [82].

While large-scale hydropower is nominally the cheapest technology in Cambodia there are very substantial associated externalities. Perhaps most significantly, a recent Mekong River Commission study found that 11 hydropower dams under development in the Mekong River basin would reduce fish biomass by around 50% once all were in operation [83].

TABLE 3:

Cost/benefit overview of various power generation technologies

Technology	Cambodian price 2015 (per KWh) –1MW+	International price range – utility scale (per KWh)	Externalities to be taken into account	Other sensitivities
Large scale hydropower	7-8 cents	4-13 cents	Downstream impacts on fish biomass resources and silt deposits for agriculture; local ecological, socio-economic impacts from reservoir clearance.	Output highly seasonal (and climate change will exacerbate); performance deteriorates as reservoir silts up (over life of BOT project).
Conventional coal-fired power (sub-critical)	9-10 cents	8-12 cents	Air pollution health impacts; carbon emissions.	Volatile coal prices – expected to increase off current low base.
Diesel/heavy fuel oil	10-25 cents	20-28 cents	Air pollution health impacts; carbon emissions.	Volatile oil prices – expected to increase off current low base.
Gas (CCGT)	N/A	7-14 cents	Air pollution impacts, carbon emissions.	Volatile gas prices – expected to increase off current low base.
Solar PV	11-12 cents	6-28 cents	Solar farms require approximately 10 hectares of land per 5 MW.	Smart grid system required, if deployed at scale, to address generation variability.
Biomass (boiler and turbine; gasification) and biogas	11-15 cents	5-13 cents	Wastewater pollution, large ash quantities, tar production.	Significant quantities of waste biomass per day; energy-focused production can compete with food production.
Wind	N/A	4.5-10 cents	Siting requirements may have impacts on local communities.	Smart grid system required, if deployed at scale, to address generation variability.
Nuclear generation	N/A	5-13 cents	Risk of catastrophic health, environmental impacts.	Radioactive waste disposal problematic and costly. Variable fuel costs.

Sources: http://www.irena.org/documentdownloads/publications/irena_re_power_costs_2014_report.pdf; www.eia.gov/forecasts/aeo/electricity_generation.cfm; www.iea.org/Textbase/npsum/ElecCost2015SUM.pdf; (international prices) and interviews with Cambodian power industry professionals, EAC and EDC for local prices.

Sambor, the largest (2600 MW) of the proposed Cambodian dams, is assessed as accounting for a significant proportion of the fish biomass loss [84]. In addition, large hydropower reservoirs are increasingly seen as major sources of methane emissions [85].

Coal-fired power also involves significant externalities, due to the health impacts of particulate pollution and chemical emissions on nearby communities. In addition to being highly carbon-intensive technology, adding to global warming, studies in the US have quantified the costs of such coal-fired power as being equivalent to 18c/kWh – which means that use of coal-fired power is uneconomic compared with other forms of generation, if all related costs are factored in [86]. It is estimated that in 2011, air pollution emissions from Thailand's coal-fired power plants were responsible for 1550 premature deaths [87].

Nuclear generation at scale can appear cost-effective (if the potentially enormous external costs of environmental impacts are excluded) but new safeguards to decrease further the likelihood of catastrophic failures will likely drive up costs. For example, the cost of new nuclear being developed by the UK is likely to be in the order of 13c per KWh [88]. The German Environmental Agency has estimated external costs alone as being between 0.107 and 0.34 euros/KWh (11.2 and 36 c/KWh).

There are sometimes concerns expressed about solar farms in terms of the land use involved. Such concerns can be exaggerated, however. Figure 11 shows the amount of land that would be involved in 700MW solar capacity.

TABLE 4:
Overview of estimated externality costs of coal, large hydro and nuclear power

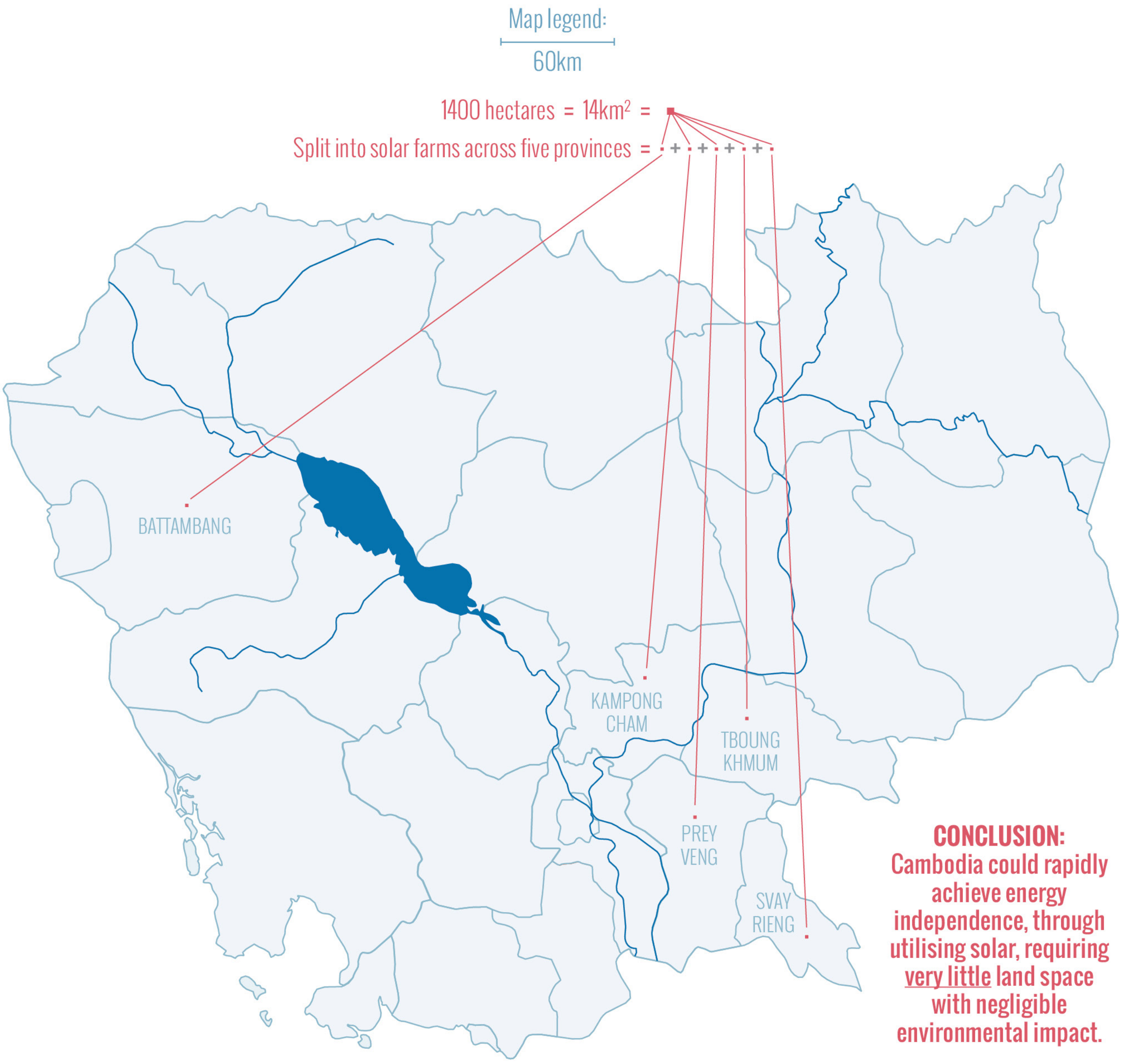
Technology	Cost c/KWh	Source
Coal	18.0	*Hidden costs of energy: unpriced consequences of energy production and use*, US National Research Council [89]
Nuclear	11.2 – 36	German Environmental Agency [90]
Large hydropower	>10.0	Derived from Working paper on Economic, Environmental and Social Impacts of Hydropower Development in the Lower Mekong Basin [91]

FIGURE 10:

(Above graphics compare land spaces relatively. Not to scale of below map.)

FIGURE 11:

Land space required to generate 1,000 gigawatt hours of electricity from solar PV by 2020



CONCLUSION:
Cambodia could rapidly achieve energy independence, through utilising solar, requiring very little land space with negligible environmental impact.

Stung Atay and Kamchay reservoirs' land footprint has been used for illustrative comparative purposes only, principally to demonstrate that a utility-scale solar facility would not take up significant land compared with other utility scale generation facilities. Stung Atay's and Kamchay's land footprint reflects the particular topography of the area, such as depth of the reservoir. Other hydropower dam reservoirs, both in Cambodia and globally may be somewhat smaller or larger relative to their generation output.

With regard to biomass generation, there are significant opportunities in Cambodia where agricultural waste (from rice farms and sugar plantations in the corridor running from the North-west to the South-east, embracing the Tonle Sap lake) provides a ready source of fuel. There are, however, minor externalities where the rice husk gasifiers themselves can be a source of pollution, including through polluted wastewater.

Technology choice sensitive to key factors

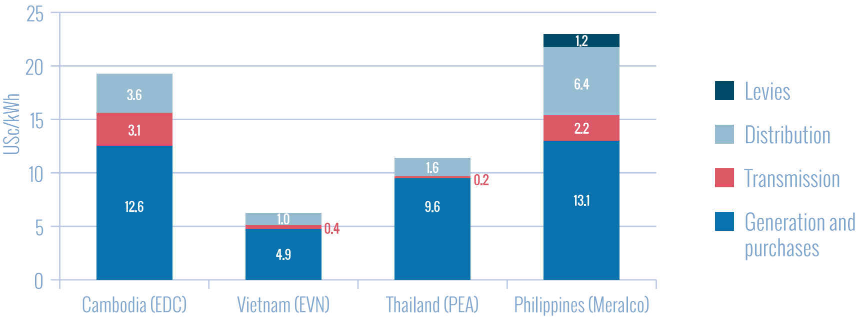
There are also other 'sensitivities' that need to be taken into account in considering whether Cambodia should look to diversify its generation mix. Fossil fuel prices are highly volatile and while, in 2015, the input costs for coal-fired and diesel generation have fallen substantially it is likely that prices will rise as global economic activity picks up. Currently low fossil fuel prices will perhaps slow the momentum of transition but, as noted previously, RE technologies which are in the early stages of development are likely to achieve greater efficiencies in the near-to-medium term and their disruptive impacts on mature conventional technologies are likely to continue.

Cambodia is experiencing significant impacts from climate change: more severe floods in the wet season and increasingly severe droughts in dry seasons. As temperatures increase and droughts become even more severe hydropower in particular will not perform as expected and the seasonal swing in output (currently hydropower is only expected to produce around 25% of rated capacity during the dry season) [92] will be exacerbated. Coal-fired power stations also require water for cooling and during hotter and dryer seasons will likely underperform significantly as well. Already the coal-fired power station operating in Sihanoukville (opened in late 2013) has not been operating as efficiently as anticipated: electricity sent out in 2014 [93] indicates that it operated fewer hours per day than anticipated. While the risk in relation to both coal and large hydro is borne initially by the contracted power plant owner, major shifts in price or rated output may drive renegotiation of contracted prices.

Distributed generation achieves network savings

A 2015 study of Cambodian electricity prices found transmission and distribution costs are high in Cambodia (see Figure 12), compared with neighbouring ASEAN countries. This reflects the RGC's investing heavily in transmission and distribution network at this time in order to achieve its commitment of 100% of Cambodian villages having access to electricity "supplied by the national grid and other sources" by 2020. Moreover, the timetable has accelerated so that 2018 is now the target date [94].

FIGURE 12:
Breakdown of electricity commercial retail tariffs - Cambodia and ASEAN neighbours [95]



Source: ECA calculations from EDC and EAC data (Cambodia, 2014), EVN data (Vietnam, 2013), EGAT and PEA data (Thailand, 2013) and Meralco data (philippines, February 2015). For EDC, the breakdown is of the tariff for small industrial customers connected to the LV network. For EVN and PEA, the breakdown of the average retail tariff is shown. For Meralco, the breakdown is of the tariff for small industrial customers connected to the LV network (General Service A category) with a consumption of 400 kWh monthly. Levies to fund cross-subsidies are only explicitly identififed in the Philippines.

A key advantage of distributed generation is that generation is located much closer to demand than is the case for traditional generation, thereby reducing significantly the need for strengthening existing or building new transmission/distribution infrastructure.

For example, the rapidly growing garment sector has driven very substantial upswings in electricity demand in Phnom Penh (so much so that Phnom Penh, in recent years representing around 50% of national demand, will represent around 60% in 2015) [96]. If this growing demand continues to be met by adding generation remote from the capital (in Koh Kong, Sihanoukville or Stung Treng) major transmission upgrades will be required in the medium-term. The low (and falling) cost of solar installation will enable greater uptake of distributed generation. As Cambodia's cities continue to grow, uptake of rooftop solar can make a positive contribution by generating during the day when Phnom Penh experiences peak demand periods (driven by the industrial and business/commercial sector – see load profile in Figure 13).

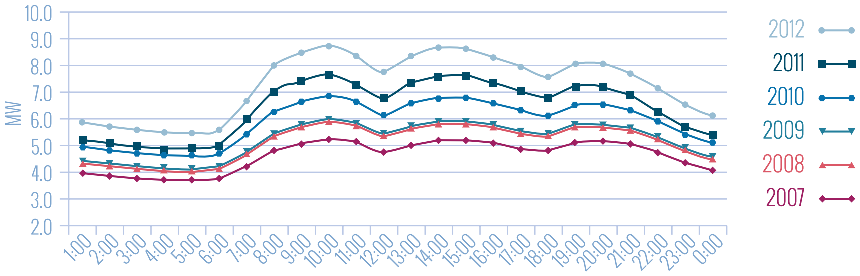
This would lower daytime demand peaks which could then be met with less generation capacity than would otherwise be required. Also, distributed generation of this kind avoids transmission and distribution losses (up to 7 8%), thus increasing the value of the distributed electricity.

While investment in solar should achieve network savings, which contribute to closing the gap in Cambodia between the current cost of solar and that of conventional generation, further investment in personnel/organizational capacity building, software and 'smart' grid management systems are required to manage increased network supply complexity and variability.

As costs are expected to continue to fall for solar it is likely to become competitive, in outright terms, with grid-supplied electricity. If costs of storage then fall to the point it becomes functional and cost-effective to operate a solar system with storage for night-time use then grid will increasingly be used only for backup. Businesses and homes would then increasingly adopt this form of electricity supply, including in Cambodia. In this context, RGC should consider preparing the power sector progressively for the coming disruptive impact of distributed variable generation. Power sector regulators can then manage the transition more effectively (and can expect international development assistance in doing so). If RGC does not manage this transition it will reach Cambodia in any event, certainly within the lifetime of long term PPAs signed with central coal-fired generators. In this unmanaged scenario far more disruptive economic and system impacts are likely.

FIGURE 13:

Average daily load profile (Phnom Penh grid), load profile (2007-12)



Source: *EDC, Cambodia - In Depth Study on Electricity Cost and Supplies* (Cambodia Chamber of Commerce report), March 2015

In Section 4 the report considers what the GMS regional picture looks like in relation to RE uptake.

4: Greater Mekong energy policy and development

Around the Greater Mekong Subregion (GMS) governments have been taking steps, in the context of promoting energy security and sustainability, to expand use of solar, wind, biomass and other forms of RE, including by setting RE technology targets. Key policies and targets are highlighted below for Thailand, Vietnam, Laos and Myanmar.

Thailand has perhaps the most comprehensive suite of policies in ASEAN. While estimates for job creation are not readily available, if the global estimate equating to around 1-in-440 of the workforce [97] is applied to Thailand's workforce of 40 million around 90,000 Thais are potentially working in RE. Spillover effects for policy, investment and economies of scale around the region could be considerable.

Thailand's power development plan 2015-2036 emphasises reduction of greenhouse gas emissions by increasing use of renewable energy and energy efficiency, alongside coal with carbon capture and storage, nuclear and hydro-electricity imports [98]. The alternative energy development plan maps out targets and initiatives to increase renewable energy use from 2015-2036. The primary focus is community and farm-oriented biomass, biogas and municipal solid waste. Solar and wind also have substantial targets for 2021. By 2036, RE is projected to account for 20 per cent of electricity capacity [99]. Plans have also been approved to liberalize solar rooftop regulations to permit unlimited exports to the grid where distribution capacity is sufficient [100].

Projects of less than 10 MW, or very small-scale power plants (VSPP), can sell directly to distribution operators [70]. Thailand's feed-in premium, or adder, provides 3.5 and 6.5 baht/kWh (US9.5c and 18c respectively) for wind and solar respectively [70]. In 2014, VSPP adders for biogas, biomass, hydro, waste and wind were replaced with 20-year feed-in-tariffs (FIT) awarded under competitive bidding [98].

TABLE 5:
Thailand renewable-energy targets 2021 [70]

Small hydro	Solar	Wind	Biomass	Biogas	Total	% peak demand
1608 MW	2000 MW	1200 MW	3630 MW	600 MW	9038 MW	23% (approx.) [101]

TABLE 6:
Vietnam renewable-energy targets 2020 [70] [102]

Small hydro	Solar	Wind	Biomass	Biogas	Total	% peak demand
3100 MW	N/A	1000 MW	500 MW	N/A	4600 MW	8.5% (approx.) [103]

TABLE 7:
Laos renewable-energy targets 2020 [70] [102]

Small hydro	Solar	Wind	Biomass	Biogas	Total	% peak demand
400 MW	33 MW	73 MW	58 MW	51 MW	615 MW	21% [104]

Vietnam is a likely contender to follow Thailand's lead, in light of good quality solar resources, rising power demand, and potential complementarities with large-scale wind development. Its power development plan 2011-2020 prioritizes renewable-energy development, reducing electricity intensity and improving energy efficiency [70]. To date, the pace of wind development appears slow [105] relative to the 2020 target partly due to the FIT of 7.8 ¢/kWh [70] being quite low for an early-stage market (but a current review is expected to increase the tariff [106]). In 2014, FITs were established for waste-to-energy and biomass combined heat and power at 2,114 dong/kWh and 1,220 dong/kWh respectively (US9c and 5c) [107]. Plans, regulation and tariffs have not yet been established for on-grid solar PV.

RE in **Laos** is targeted to supply 30 per cent of total energy consumption by 2025, primarily biodiesel, bioethanol and small hydro (large hydro is focused on export to Thailand and Vietnam). The period to 2020 will focus on building up a competitive biodiesel and bioethanol industry, from securing feedstocks through processing to distribution. Thereafter, the biofuel sector aims to be fully competitive for regional exports.

In **Myanmar**, hydro and thermal are the primary focus but the Government intends to develop wind and solar, improve energy efficiency, and facilitate community participation. In particular, it aims to develop 472 MW of small hydro by 2016. Other RE targets have not yet been established and there are no specific incentives for RE uptake.

Risks and returns of large hydro power development for regional sustainability

Development of large hydro power plants is a defining feature of the Mekong basin in the 21st century. Activity is most intense in Laos which has understandings to supply Thailand with capacity of 7,000 MW by 2015 and Vietnam with 3,000 MW by 2020. The Lao Government is planning for at least 10 GW of installed capacity, across 74 projects (including 29 currently operational plants), to be in place by 2020 [108]. It also intends to develop all hydro power opportunities (investment approval granted for 26,147 MW across 357 projects) by 2030 to benefit the country and ensure sufficient supply for the region [109] [110]. Projects range from a few megawatts to the $3.8 billion 1,285 MW Xayaburi dam, the first across the Mekong mainstream in Laos.

Evidence from around Asia indicates hydropower projects are often late and over budget putting competitiveness and even financial viability into doubt, the scale of which could pose macroeconomic risks to developing countries [111]. Emissions from large hydropower projects in the tropics are the subject of much uncertainty, appearing to be highly site specific (warranting more research), but concerns are growing that methane emissions from dam reservoirs are much more significant than previously thought. Hydropower emissions also have to be compared with alternatives such as coal, solar and wind [112]. Large hydropower projects in Brazil, where conditions are analogous to the Mekong, may in fact be a considerable source of greenhouse gases at least in the first ten years of operation and possibly longer [113]. Should hydropower emissions receive greater attention from the UNFCCC the implications for national carbon budgets and carbon-pricing of electricity in the Mekong could be significant.

In addition, the security of hydropower output weakens as global temperature rises with increasing greenhouse gas concentrations intensifying disturbance of rainfall patterns. Detailed assessment of climate impacts on hydropower dams in the Mekong is difficult and subject to considerable uncertainties. Dams

Evidence from around Asia indicates hydropower projects are often late and over budget putting competitiveness and even financial viability into doubt.

in the Mekong designed for historical hydrological conditions may be ill-matched to future drought and flood patterns. Expected increases in the frequency and duration of droughts could cause output to fall below contractual volumes. Already, in Cambodia several dams are producing far less electricity then feasibility studies projected, including the Kamchay dam in Kampot province, where output fell as low as 10% capacity during the 2013 dry season. Water inflow timing, evaporation and increases in sedimentation will also affect production. More frequent, severe floods increase risk of catastrophic dam failure, posing threats to villages and towns downstream [112]. Underperforming hydropower dams will mean delayed investment payback and revenue shortfalls for government budgets. In short, the cost, emissions and security risk profile for large hydro power projects in the Mekong is deteriorating.

Gains in electricity supply from hydropower projects must also be considered against local and downstream losses. Fisheries, farming, food security and the Mekong Delta are at risk in Cambodia and Vietnam because multiple upstream hydropower dams disturb flood cycles, nutrient flows, sediment transport and migratory fish breeding [114] [115] [116]. Dams upstream have already affected seasonal flow downstream [117]. Impacts on hundreds of migrating fish species are critical because they are a major source of protein for many people in the Mekong basin [118]. Farmers and fishers downstream face declining yields, incomes [119] [115] and in some cases direct health impacts [120]. Economic and social returns of upstream dams would need to be assessed as being greater than the cost of potential impacts downstream, for example to Mekong Delta food exports (worth $10 billion annually) [121]. Existing and prospective transboundary impacts such as these on ecologies and livelihoods have already raised considerable tensions between Cambodia, Laos, Thailand and Vietnam. Cumulative impacts of multiple hydropower dams will only increase as climate change intensifies – heightening pressures on agriculture, livelihoods and prosperity.

It may be possible that large hydropower projects can generate net benefits but it is important for countries to carefully assess all costs and benefits, including transboundary effects and the effects of climate change over time. In some cases reducing impacts (through alternative designs, focused on improving fish migration outcomes) may be cost effective and sustainable; in others it may pay to maintain the option for hydropower development later while focusing initially on energy resources with lower impacts on food security and economic development [122].

Prospects for regional power trade

Large hydro and thermal power projects initiated today in the Greater Mekong face increasing competition from numerous similar projects and contend with softer electricity demand than official projections have forecast. Certainly the volume of projects lined up in Laos and Myanmar raises the question of regional saturation: not all proposed projects will prove viable if GMS supply outstrips lower than forecast regional demand.

Cumulative impacts of multiple hydropower dams will only increase as climate change intensifies - heightening pressures on agriculture, livelihoods and prosperity.

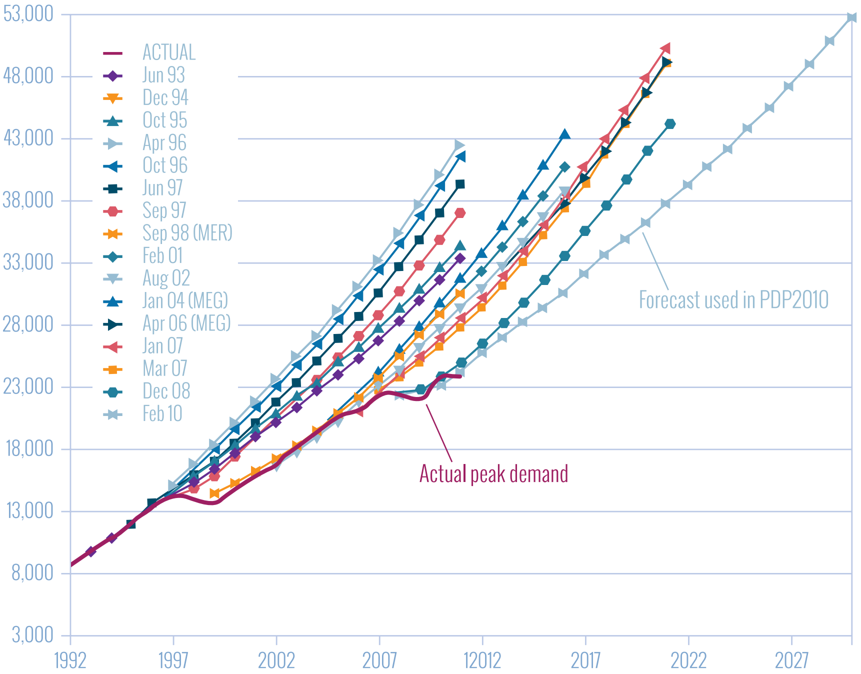
Thailand, for example, has consistently over-estimated demand (see Figure 14). Consequently, the reserve margin is around 35 per cent, potentially rising towards 40 per cent as more hydro projects come on line in Laos. To reduce potential economic losses plans have been put forward to build transmission lines to export power from Thailand to Myanmar [123] [100].

In addition, RE installed costs (and storage costs) are expected to continue to decline and residential and commercial solar systems will become attractive regardless of policy incentives. Current price trends suggest this may occur within the next decade. Were solar to deploy across most roofs in Thailand and Vietnam, combined with storage and dynamic demand side management, it is conceivable that (even with ongoing strong economic growth) load on central grids could stabilize and possibly even decline (as in Australia) by the 2030s. Investors in central generation, which requires payback periods of well over a decade, will need to weigh risks and opportunities carefully in this fluid technology cost environment.

The outlook for domestic electricity production and regional power trade has never been so uncertain due to great changes in technology which are reshuffling the merit order moving wind and solar to the left, thermal and potentially large hydro to the right. If demand falls below assumptions some projects will necessarily earn less revenue than expected. In the extreme, bilateral power purchase agreements may need to be renegotiated.

There are clearly risks, therefore, in Cambodia's plan to scale up central generation significantly in anticipation of being able to export hydropower surpluses during the wet season (with coal-fired generation as back up for the dry season). Current RGC forecasts (Figure 2) are for electricity supply to exceed demand for much of the year from 2018 (when power imports are forecast to decline to zero, effectively, outside a few months in the dry season). Given the uncertainties, it may be prudent for the RGC to revisit current plans for significant scaling up of hydropower in the 2020s and even more significant fossil fuel generation over the next 5 years (up to 530 MW of coal-fired power by 2020) and significant gas-fired power in the 2020s.

FIGURE 14:
Thailand's forecasts of future peak electricity demand over time [124]



In Section 5 the report considers possible Cambodian targets for RE for generation supply in the period to 2025.

5: Support for/barriers to distributed RE technology

Although uptake of RE in Cambodia has to date been on a small scale and largely focused on off-grid generation, the lessons learned from the programs already implemented are valuable in considering the scope for scaling up RE going forward.

Lessons learned

Off-grid: the initial World Bank-funded REF program (which concluded in 2012) faced significant hurdles in supporting uptake of 12,000 **solar home systems** (SHSs) by rural households. In particular:

- lack of national standards for SHSs, including batteries, meant the SHS equipment supplied was in some cases not fit for purpose;
- this led to a relatively high rate of underperformance, exacerbated by intermittent post-installation maintenance – and this resulted in solar gaining a poor reputation in a number of regional areas; and
- provision of bulk-purchased SHSs, on a heavily subsidised basis, meant that private sector providers/installers were often sidelined, slowing the development of Cambodia's solar industry.

More recently, the rapid rollout of national grid in Cambodia has meant that many potential purchasers of SHSs have decided to wait for the grid, which EDC is now aiming to complete as soon as 2018, including by introducing subsidies for existing diesel minigrids.

The EU/AFD-supported Good Solar program aims to work with the private sector to develop standards to improve SHS system design and installation as well as after sales service. It is also seeking, through a range of communication strategies, to improve understanding of solar technologies amongst Cambodia's regional population. The REF program, now incorporated into EDC, is also aiming to improve the quality of systems it provides. A 2013 study [125] found that Cambodia had a potential market of 250,000 households likely to be interested in purchasing a solar home system and able to purchase one by borrowing from the MFI sector.

Solar battery charging stations (substituting solar for diesel) have not to date proven attractive to local entrepreneurs as the payback period for capital investment has been extended due to the fall in the price of diesel. SHS prices will, however, likely fall further, making payback periods more attractive.

On-grid, the regulatory environment has not been supportive of renewable generation – where the unclear legal status of excess generation (that which is not consumed and is sent out to the grid) impedes uptake. It has been possible to put in place power purchase agreements (PPAs) between EDC and RE generation in isolated instances (eg net metering for the Don Bosco school **solar rooftop installation** and for **bagasse waste-to-energy** plants in Kratie and Kampong Speu, where dry season generation is netted out from wet season consumption, reducing overall costs). There is, however, no clear policy for new investors.

Support for uptake of **biomass gasifiers** (using rice husks) and development of a Cambodian gasifier manufacture industry has not yet proved successful, as envisaged, in driving local private-sector led investment. The economic case for substituting rice husk gasifiers for diesel generation was previously strong but has now weakened, given the cost of diesel has fallen around 50% in 2015 and given that the waste can now be sold in Thailand where biomass generation attracts a feed-in tariff. The rapid rollout of grid has also meant some rice millers have opted to connect to it, as payback periods for gasifiers are now longer than the previously envisaged 3-4 years. Use of low quality gasification equipment has also resulted in more significant direct pollution impacts than anticipated.

Similarly, **biodigesters** on a commercial scale (producing power from gas from farm animal waste) are also less likely to displace diesel-powered generation at 2015 diesel prices without some form of subsidy.

There has been limited experience with **wind generation** in Cambodia with only one large turbine erected, with EU and Belgian support, in Sihanoukville to help power its port. In addition to mechanical issues this turbine's poor siting contributed to its not generating to its capacity rating.

While there have been learning challenges associated with Cambodia's implementation of RE, the trialling of a number of technologies on a relatively small scale has provided valuable lessons for any decision to scale up RE levels in the power supply mix. Trialling these technologies has also identified a number of key constraints holding back scaled up RE adoption.

Barriers to renewable generation uptake

Industry, development partners and CSOs/NGOs have identified [126] a range of barriers faced by investors in renewable generation.

The Government is yet to set a renewable energy/generation target: it is not yet clear that the Government strongly supports uptake of variable renewable energy (RE) generation in practical terms, although it has articulated commitments [127] to pursuing green growth/low carbon development pathways. The total uptake of RE supply to Cambodia to date represents less than 35 megawatts, compared with more than 1200 megawatts of large hydro and coal-fired generation under the PDP since 2009. MME projections for development of the power supply mix to 2030 is made up almost entirely of fossil fuel and large hydro generation.

Unlike a number of its GMS neighbours (Laos, Thailand and Vietnam), RGC has not yet set official targets for power supply to come from RE sources. RGC energy agencies have informally suggested that 100 MW, or around 10% of 2015 final electricity demand could be incorporated in Cambodia's power supply mix in coming years but there has not been a clear articulation of a strategy for how this could be integrated with existing supply nor what technology types would be involved, except that officials have indicated a forthcoming 10MW solar generation facility to be constructed in Bavet would serve as a trial for solar uptake at scale, potentially up to 100MW [128].

The ongrid RE regulatory environment is unclear: legally, a licence from EAC is required to generate and supply

The trialling of a number of technologies on a relatively small scale has provided valuable lessons for any decision to scale up RE levels in the power supply mix.

electricity. In practice, Government does not require a licence for organisations installing small-scale renewable generation (less than a megawatt) where the electricity generated is only consumed by the organisation itself and any excess electricity is not sent to grid.

The economic case for installing RE generally relies, however, on obtaining a financial return, in some form, for all electricity generated. Commercial scale organisations, such as large offices and schools have been deterred from investing both by the lack of formal legality and not being able to monetise the value of excess electricity sent to grid.

There has also been a lack of clarity in relation to larger scale generation. In 2014 an international investment firm and an international solar supplier sought to develop a 100MW solar power generation facility. The proposal did not proceed as there was no clear tender process for additional supply under the power development plan. EDC has indicated it is preparing tender documentation for supply of 10 MW from solar generation in Bavet (for release by end-January 2016) [129] and it would be valuable to set out a schedule for major tender bids for the next 5 years, open to a range of technology types.

<u>Feed-in tariffs and net metering</u>: to date EDC has generally not recognised the value of distributed electricity provided to the grid. There is no feed-in tariff (FiT) but there are individual net metering arrangements (customers are charged, over a billing period, for their electricity consumption less any excess electricity sent out to the grid) for a few facilities, including the Don Bosco solar equipped school in Sihanoukville. Such arrangements mean select organisations are effectively paid the retail price for electricity they provide to the grid.

An approach is needed that recognises the value for EDC of additional daytime electricity supplied close to the point of consumption. Significant uptake of distributed generation would help meet daytime demand peaks (reducing the need for additional central generation and for consequent investment in network upgrades) and boost supply during the hot/dry season when hydropower output is much lower. Daytime distributed generation is also complementary with using existing large hydroelectric power more during evening peaks.

A more equitable approach would provide appropriate payment for all RE suppliers of electricity to the grid, involving:

a) EDC purchasing RE at a Fair Value Tariff (FVT) rate (representing the wholesale electricity price with an additional amount to recognise the value EDC derives from this energy)
    - EDC could then onsell this electricity at the standard retail rate, generating a similar level of revenue as electricity purchased from central generation.

b) Until such time as an appropriate FVT can be determined and 2-way meters installed (to measure both consumption and generation sent out), the existing net metering approach should be extended to all suppliers where consumption is

Daytime distributed generation is also complementary with using existing large hydroelectric power more during evening peaks.

regularly larger than the quantity sent out to the grid;

c) for RE facilities where the primary purpose of the facility is to supply electricity – either to EDC, an REE or other EAC-licensed provider – tariff rates, recognising the additional benefit of distributed generation close to the point of consumption should be agreed in the context of power purchase agreements.

Introduction of an FVT would likely need to be done as part of a development package to assist Cambodia work towards a RE target, including by supporting uptake of more sophisticated metering and use of smart grids. Extending net metering to all RE suppliers (if net consumers of electricity) could be done rapidly as existing meters can be used to assess the net amount of electricity consumed in a billing period.

Access to finance: Cambodian banks have to date been very cautious about investing in RE. For example, despite relatively short term payback periods banks were not prepared to lend to rice farmers for purchase of rice husk gasifiers, unless very substantial collateral was provided. This has contributed to biomass being driven largely by development partner support programs despite there having been a business case for uptake. The business case is now particularly strong for solar at multi-megawatt scale but banks are not seizing the opportunities now available. A concessional loan revolving fund focused on RE uptake, backed by development partner finance and in partnership with the Cambodian banking sector, would help address this issue.

Taxation issues: sustainable biomass energy products (such as sustainable charcoal briquettes) have recently been exempted (on a case by case basis) from paying VAT, recognising the value of promoting sustainable energy. Solar panels and equipment, however, are still subject to VAT (and 7% import duty). Given electricity purchases are exempt from VAT it is inappropriate for solar electricity generating equipment to be subject to VAT (which would normally be passed on to the end-consumer but cannot be passed on in this case).

Potential for enhanced RE uptake in different sectors

The costs and benefits of various RE technologies (Table 3) and the ADB's findings regarding different technologies' potential make clear that solar, biomass and biogas generation all have strong potential to form a much larger part of the power supply mix in the near term.

Opportunities vary according to the sector involved but all technologies would benefit from the RGC putting in place a target for RE uptake and a suite of enabling policies to support their uptake over the next 5 years. In light of RGC plans under way to accelerate grid extension to 100% of Cambodian villages by 2018, there are now opportunities for significant scaling up of ongrid distributed generation, particularly from rooftop solar. Also, with 30% of Cambodian households currently not scheduled to have access to the grid

Opportunities vary according to the sector involved but all technologies would benefit from the RGC putting in place a target for RE uptake and a suite of enabling policies to support their uptake over the next 5 years.

Potential targets for scaling up sustainable power generation

Officials have indicated informally that RGC could consider looking to scale up RE, particularly solar, to 10% of 2015 peak demand capacity (around 100 megawatts). A more ambitious target would be one representing 10% of anticipated peak demand in 2020 (1556 MW) – this would represent building from around 35 MW currently installed non-large hydro RE to 156 MW in 2020.

Cambodia could also, however, set a longer term target for 2025, of 10% of electricity supply (in gigawatt hours (GWh) sent out as per Figure 2). On MME's current forecast for 2025 of 12,000 GWh that would represent 1,200 GWh, which would require around 850MW solar generation capacity (if solar alone were used).

In this case it would make sense for the 2020 target to be in the order of 350MW of RE.

Even the larger of these two proposed targets would not radically change Cambodia's power sector. For example, 1200 GWh of renewable energy would mean that investment in around 220MW of coal-fired generation could be avoided by 2025. In order to scale back significantly the amount of coal and/or large hydro generation currently envisaged for the power supply mix Cambodia would need to implement its 2013 draft energy efficiency strategy (to reduce forecast demand) and adopt a target similar to Thailand's target of having renewable energy represent 25% of all energy use by 2025.

until 2030, there remains considerable scope for further rollout of solar home systems and other off-grid renewable energy generation solutions.

The analysis below is intended to illustrate how potential uptake in different market segments could contribute (if an enabling environment is put in place) to reaching a target of 156MW in 2020. It is indicative only and focuses on solar as this technology is emerging as highly cost-effective, given Cambodia's good insolation profile. Biomass and biogas technologies can also play substantial parts.

Industrial sector (greater than 1MW): many of the garment factories clustered on the periphery of Phnom Penh are suitable for housing numerous solar panels. In the manufacturing sector as a whole, there are tens of facilities whose power consumption would warrant installing solar panels at >1MW scale [130]. Similarly, the Phnom Penh Special Economic Zone (SEZ) and other SEZs have tens of major industrial operations in a similar position. At this scale, solar can supply electricity in Cambodia at the equivalent of around 12 cents per kWh (or even below 10c with the right financing structures in place), while providing a competitive internal rate of return on investment [131]. This is significantly less than 17.2c per kWh which industrial and commercial customers will pay for grid-supplied electricity in 2016.

It is also very close to being competitive with wholesale electricity supplied by coal-fired power stations. These currently charge EDC around 10c per kWh and lose up to 8% in transmission and distribution losses en route to Phnom Penh consumers, making the effective wholesale price of coal closer to 11 cents/kWh, not taking into account carriage charges by transmission and distribution companies (which contribute to keeping Cambodian retail prices very high compared with ASEAN neighbours). Moreover, developing a significant quantity of new generation at the edge of Phnom Penh would also likely enable deferral of transmission upgrades required with the next decade, at considerable savings to EDC. It would therefore be appropriate for EDC to support uptake in this sector through making net metering arrangements available to factories' rooftop generation or, alternatively, to establish a FVT equivalent to the 11 cents plus a premium for network savings (effectively placing it between EDC's substation rate of 12.9 cents/kWh and the full commercial retail rate, 17.2c in 2016).

Potential by 2020: 40 Phnom Penh factory roofs housing 2.5MW on average could provide **100MW** of generation for EDC, the portion of which was not consumed could be onsold by EDC at the retail rate.

Commercial, business and Government buildings: installations between 20 and 100kW would likely be involved for medium-sized office buildings, with the price per KWh being close to competitive with the 780 riel (19.5c per kWh) uniform EDC retail price being introduced in Phnom Penh in 2016. Introduction of net metering arrangements would likely leverage very significant private sector investment.

Potential by 2020: assuming 500 offices installed 40kW on average, EDC would benefit from an additional **20MW** of generation close to point of consumption.

Households – on and offgrid: moderately well-off *urban households* would likely look to install 1-5kW systems. Given many households' peak consumption is during the evening net metering would work well to leverage private investment in this sector.

Potential by 2020: if 10,000 households installed 1.5kw systems on average then a further **15MW** would be available close to the point of consumption.

Rural offgrid households currently have very limited access to electricity. The RGC's 2030 target (70% of households by 2030 to have access to grid electricity) will still mean around 820,000 households in Cambodia will need access to some other form of electricity. Good Solar and the REF aim to reach up to 40,000 of these under their current programs. There is certainly scope to scale up these programs to ensure that the majority of such households have access to electricity via an SHS. Provided Good Solar and REF continue to show positive results, development partners could look to increase their commitments substantially.

Potential by 2020: if 200,000 additional homes could access SHSs (of around 100W) that would provide additional generation of **20MW**.

As is evident from the above, major scaleup of solar across a range of sectors could potentially yield 155MW of

Developing a significant quantity of new generation at the edge of Phnom Penh would also likely enable deferral of transmission upgrades.

additional generation by 2020. This would readily achieve the lower target proposed above. If a utility scale solar facility of 100MW and biomass opportunities are also deployed at scale the higher target of 350MW by 2020 could also be achievable.

Support strategies for achieving RE targets

RGC officials have indicated publicly that 10% variable renewable energy represents the most the Cambodian power sector can accommodate at this stage of its development and have expressed concerns that moving beyond 10% could create instability on the grid. There is also concern that significant capacity building amongst industry and RGC agencies will be required to support integration of RE into existing power sector management systems.

Development partners are, however, positively disposed towards supporting significant scaling up of RE in the power mix, particularly post-COP21, and can look to develop with RGC a strong policy and program package that can facilitate RE integration. If there is high level Government commitment to enhancing sustainable power generation through a target, there will likely be significant opportunities to access international support via climate finance funds, such as the Green Climate Fund, ADB's Scaling Up Renewable Energy Program (which Cambodia is already engaged in), USAID's Sustainable Mekong Energy Initiative, Australian aid's 3i (including an electricity infrastructure initiative) and AFD's ongoing strong support for Cambodia's power sector development.

In addition to supporting RGC to address the key constraints outlined earlier in the section, such a package should include the following capacity building elements:

- a substantial concessional loan revolving fund focused on addressing access to finance to overcome capital barriers for RE uptake;
    - such a fund could also address specific opportunities for RE uptake where information failures mean private sector investment is not taking advantage of these opportunities – eg provision of solar panels to power mobile telephony towers (currently underutilised).
- education and training of MME, EAC and EDC staff in relation to managing:
    - a range of technologies, including RE, as part of electricity supply;
    - net metering and fair value tariffs;
- upgrade of existing grid management technology to include appropriate RE 'smart' grid monitoring/management technologies;
- installation standards to ensure performance and safety of RE equipment; and
- enhanced vocational training to address growing skills needs in relation to installation of solar panels and biomass generation technology in particular – to ensure safety, reliability and performance maximisation.

If there is high level Government commitment to enhancing sustainable power generation through a target, there will likely be significant opportunities to access international support.

Conclusion/next steps

This report has identified that there are significant opportunities but also significant risks for Cambodia around its policies for strengthening the security, reliability, cost-effectiveness and sustainability of the rapidly developing power sector. RGC's current policies for expanding generation supply from 4,000 GWh in 2015 to 12,000 GWh by 2025 rely almost entirely on further investment in large hydro and coal-fired power plants (with gas-fired plants beginning to come on stream from 2024). Current non-large hydro renewable generation currently supplies less than 100 GWh and significant expansion of non-large hydro renewable generation is not in the current policy planning.

Elsewhere in the world, the disruptive impact of renewable energy technologies is being felt by conventional power sector business models. In particular, as more and more businesses and households take advantage of the increasingly competitive price of solar rooftop technology, the nature of power supply is changing: in China, Europe, the United States, Australia and in Uruguay and many developing countries. The overall result for these economies is positive as considerable savings accrue to individual firms and households and less investment will be required in physical electricity infrastructure. For power utilities that continue to rely substantially on conventional central (often fossil fuel) generation business models, power revenue is likely to be significantly affected unless they can diversify into service-oriented organisations rather than straightforward sellers of electricity.

Cambodia faces technical, economic and political risks in coming decades if it does not begin to prepare for these changes.

Technical breakthroughs could drive uptake of renewable energy very rapidly as lower costs and increasing utility make home generation (and possibly storage) increasingly more competitive with central generation. 'Smart grids' would then be necessary to manage variable electricity supply from a much larger proportion in the generation mix of solar, wind and other variable technologies as well as the likelihood of consumers beginning to use home 'power packs' and electric vehicles as storage devices. This is a technical challenge that Cambodia's power sector regulators can embrace early in order to prepare for changing consumption patterns or they may have to play catch up in the 2020s as thousands of households and businesses move independently, and rapidly, in this direction.

Economically, power providers face a challenge to embrace the new realities. Forecasts for business opportunities in Europe's electricity sector to 2025 suggest that overall there will be considerable growth as new renewable and smart grids technologies and services are promoted by innovative businesses but businesses relying predominantly on fossil fuel generation will face losses. If very low fossil fuel prices continue, transition may well be slowed but the trend is clear.

Politically, as Cambodia transitions in 2016 to a lower middle-income country, there will be higher domestic

Cambodia faces technical, economic and political risks in coming decades if it does not begin to prepare for these changes.

expectations of equitable access to increasingly affordable and secure electricity – which does not involve major environmental damage. Additional RE generation at scale would certainly support RGC's overarching energy security objective, as it would be available at times of hydropower seasonal lows and reduce the need for imported electricity.

There are also significant opportunities for Cambodia to scale up renewable generation cost-effectively.

Ongoing steeply downward technology price trends, particularly for solar PV technology, as well as ongoing relatively high electricity prices in Cambodia suggest that many Cambodian business (and, before long, households) will begin to invest in their own generation. Already some large-scale industrial facilities (where electricity consumption is in the order of 1 MW peak demand) could invest profitably in renewable generation – allowing them, in the case of solar, to pay less than their current costs. To kickstart such investment, RGC could establish a positive enabling environment, in line with recommendations outlined below.

There is considerable international finance sector interest in looking for 'bankable' renewable energy projects in the Greater Mekong Subregion, including Cambodia. As global emissions reduction ambition increases following COP21 there will likely be increasing incentives for developing countries, such as Cambodia where energy infrastructure is still developing rapidly, to consider ambitious pathways towards their power sectors having the majority of their generation come from (non-large hydro) renewable sources. Bilateral development partners and international funds, such as UNFCCC's Green Climate Fund, the Asian Infrastructure Investment Bank, the multilateral development banks' Climate Investment Fund and the Global Environment Fund are all looking to leverage private sector investment to accelerate uptake of renewable energy. Projects will, however, be more readily considered 'bankable' where there is a clear policy and regulatory framework in place that will support uptake.

Cambodia has supported renewable energy uptake in the margins over the last decade but RE is yet to take off as a core part of the power sector. There are some important actions that the RGC could consider in order to hedge against the risks and to take greater advantage of opportunities.

Next steps

In particular, RGC decision makers could assess what level of target for renewable generation Cambodia could adopt for 2020 and 2025 and what enabling environment is needed to support achieving such a target. The table below sets out some key actions which RGC could consider to create an enabling environment for major scaling up of RE uptake. These would represent a step-by-step approach that would prepare Cambodia better for the power sector changes of the coming decades.

RE generation at scale would certainly support RGC's overarching energy security objective, as it would be available at times of hydropower seasonal lows and reduce the need for imported electricity.

Key points for RGC to consider

1. Given much lower technology costs now available, formalise an interim renewable energy generation target for 2020 – pending a more detailed study of what would be a cost-effective but ambitious level of RE to integrate into the power mix by 2025. Possible interim targets (noted in this report) include:
   - 100MW before 2020 (representing 10% of peak demand in 2015 of around 1000MW)
   - 156MW in 2020 (representing 10% of peak demand in MME's low case (+20% reserve margin) forecast for 2020)
   - 500 GWh for 2020 (representing a mid-term target for reaching 1200 GWh of generation in 2025, ie 10% of MME's forecast generation for 2025).

2. Clarify the regulatory environment for Cambodian and foreign investors, as well as development partners looking to leverage private sector investment flows.
   - Formally recognise in law the right of onsite generation, notably rooftop solar, to supply electricity for own use and to supply excess electricity to the national or local grid.
     - Establish, in 2017, appropriate 'fair value tariffs' (per kWh) for electricity sent out - following a detailed study of the value sustainable generation close to the point of consumption represents.
     - Pending establishment of specific fair value tariff rates as above, a 'net metering' approach, as proposed by the Solar Energy Association of Cambodia to MME in 2015, should apply (whereby usage over a billing period reflects consumption from the grid minus electricity sent out).

3. Develop a concept note to seek international development support to establish a concessional loan rolling fund which could address initial capital barriers.

4. Further develop a proposal for development assistance to support RGC with:
   - education and training of RGC energy agency staff in relation to managing:
     - a range of technologies, including RE, as part of electricity supply;
     - net metering as a stepping stone to fair value tariffs;
   - upgrade of existing grid management technology to include appropriate RE 'smart grid' monitoring/management technologies;
   - installation standards to ensure performance and safety of RE equipment; and
   - enhanced vocational training to address growing skills needs.

5. Consider removing VAT and import duty from solar generation equipment, consistent with decisions to support sustainable energy by exempting sustainable biomass energy products from VAT, and also recognising that purchasers of solar equipment cannot pass on VAT costs as part of electricity prices.

Further research required

1.	Detailed study of what would be a cost-effective and achievable (but ambitious) level of RE to integrate into the power mix by 2025, given contemporary pricing directions. a. assessing also emerging renewable energy technologies (with improving generation efficiency) and likely timeline for power storage to become cost-effective in Cambodia. b. assessing what mix of renewable energy technologies, at what scale, would be required to meet 2025 forecast demand without additional (post-2020) investment in fossil fuel and/or large hydro generation.
2.	Detailed study of what is the value of sustainable generation (close to the point of consumption) – in order to establish, in 2017, appropriate 'fair value tariffs' (per kWh) for electricity sent to grid by owners of RE generation.

To assess also whether there would be (positive or negative) revenue implications for EDC from the introduction of fair value tariffs.

Appendix 1: Energy Transition

The energy system is highly complex, emerging from a wide range of diverse interests, problems and opportunities. A comprehensive explanation of the dynamics lies in incorporating and synthesizing multiple perspectives. Brevity requires focusing on one aspect and considering one theory to frame developments. Currently, the question of socio-technical transition from a system largely employing fossil fuels to one powered mostly by solar, wind and water is the most prescient. As a wholesale transformation of a critical sub-system of society it should trigger structural change in the social system which has historically co-evolved with characteristics of the dominant energy source [1].

A framework for understanding socio-technical transitions is the multi-level perspective. A transition is analyzed by dividing the socio-technical system into three levels. At the micro level innovation occurs in social niches, figurative places where people, from small cloistered groups to loose networks spanning public and private domains, explore novel or even radical formulations of technology searching for superior performance. The meso level is the governing socio-technical regime of norms, rules and expectations emerging from the ways of thinking and interpreting world held by engineers, scientists, policy makers, regulators, users and interest groups.

The socio-technical regime is usually a stabilizing force for the incumbent development pathway. At the macro level the socio-technical landscape is comprises deeply-embedded cultural patterns, economic structure, political economy, and beyond that resource endowments. Change is slowest at the macro level and fastest at the micro level. When powerful innovations emerge from niches and landscape changes generate sufficient pressure to destabilize the regime a period of transition unfolds as a new regime takes shape around novel technologies compatible with landscape changes [2].

Like any model it has strengths and weaknesses and should not be taken too literally. Applying the framework to reality is not so simple because interactions between the levels, which might also be thought of as domains, appear far less clear cut. People usually hold a rich range of relationships, interests and motivations. Many people operate on more than one level. The multi-level perspective is nevertheless valuable for drawing attention to the fact that technology is not an end but a means employed within and developed through social processes.

It is a critical point because renewable-energy technologies are opening up the energy system to active participation by a much wider range of people, groups and communities [3]. A fundamental change confirming that a socio-technical transition is underway with profound consequences. The perspective also helps explain the interaction of renewable energy technologies – niches – and climate change – landscape – with global and national public and private policy – landscape. Policy has to accommodate changes in technology and climate while simultaneously acting as a force exerting some influence, but not necessarily control, over what happens in technology and climate.

Today's energy transition is also fundamentally different from previous transitions because it combines technology, which delivers private benefits, with a preference for environmental quality, which is a public good [4]. To overcome the free-rider problem [5] and deal with the urgency of emissions reduction the transition requires direction from government. Smart and stable policy is also required to ensure the transition is rapid rather than unfolding over several generations as has historically been the case [6] [4] [5] [7] and call into being a panoply of new technologies and materials that may produce a third industrial revolution or catalyze a sixth long wave of economic development [4].

The energy transition is also a transition for markets, prices and regulation. Competitive technology costs and the opportunity for consumers to express preferences in markets are important factors supporting transition. Nevertheless, because environmental quality is a public good consumers are unlikely to express their preferences in the market unless the alternative offers greater near-term private benefits without incurring significantly greater cost [6].

What does energy transition mean for policy and investment in development latecomers such as Cambodia? The answer lies in considering the niche and landscape, followed by the regime of international policy. The potential macro-economic benefits of fixed-price renewable energy also have to be considered before finally turning to the risks and opportunity for an energy leapfrog.

Breaking out: from niche to critical momentum

Renewable energy technologies have over the last decade or so matured sufficiently to break out of niches attaining critical mass and momentum to disturb the socio-technical regime. Stability is giving way to flux, which may move through various stages and periods of temporary stability until the regime is reformed or replaced [2].

Over the last decade technologies to harness renewable energy resources have expanded at unprecedented rates [8]. Solar, storage and wind technologies exhibit attractive returns to scale because of mass production. For example, every doubling of global production reduces solar costs by 21 per cent. Electric-vehicle lithium-ion battery costs are falling around 8 per cent annually on track for $200 per kWh of storage by 2020 against over $400 in 2010 [9]. Conventional power plants often see costs rise because much of the work is not standardized and is done on site, rather than in factories. Electricity produced by solar and wind is usually sold for a fixed price fixed because most of the cost is capital expenditure providing certainty for investors and consumers.

Complementary technologies, facilitating deployment of solar and wind, such as advanced batteries, power electronics, and control systems, are subject to similarly advantageous cost-performance dynamics. Solar's deployment potential is unmatched by conventional power plants because its modular form is suitable for almost limitless opportunities scaling from watts to megawatts [10]. By 2050 it may be viable for wind, water and solar to power most countries, including Cambodia [11].

Distributed generators and storage are transforming the design paradigm for electricity systems [12], massively increasing the number of participants, decentralizing control and power from a few agents to many depending on the regulatory and political context. In Germany over the last decade several million households and small firms have become independent power producers by turning roofs and other marginal spaces into solar power plants [8]. New possibilities are emerging for sustainable and resilient cellular power-system architectures tailored to local resources and needs.

Perhaps most remarkable is that in the 21st century power systems are no longer built only by utilities following top down projections and plans, often heavily influenced by the industry. Instead power systems are developing simultaneously from the base up in a process of self-organization because technology is now accessible to consumers and communities, as we see for example in Australia, Germany, India and Kenya. Consumers are exercising choice and in doing so are evolving from customers to competitors and collaborators. Such a profound development undermines the basic assumptions of conventional power-development plans and investments. Compared to the static central-radial power system model of the 20th century power systems will be strikingly more complex, dynamic, diverse and efficient in the 21st century.

Stress and strain: climate changes the landscape

Climate change is a symptom of a fundamental shift in the quality of the environment due to human consumption of energy, disturbing the landscape generating increasing stresses and strains for the socio-technical regime. Governance for technology selection, manifesting through policy, has to incorporate new environmental constraints restrict and reorder optimal energy-resource selection, which in turn determines technology options (figure 2).

Climate change has triggered a range of mitigation and adaptation responses from governments and utilities worldwide. Mitigation policies employ a range of market and regulatory instruments to reduce greenhouse gas emissions plus initiatives and incentives to stimulate research, development and diffusion of behaviour and technology, for example greater efficiency, research grants, and feed-in-tariffs for solar and wind. Utilities and commercial consumers are also establishing mandates and implementing strategies to reduce emissions from their operations for several reasons, including concerns about competitiveness and carbon-pricing plus regulatory and reputational risk.

Adaptation policies aim to ensure energy infrastructure is resistant to climate change by specifying standards, risk assessments and timeframes for remedial action if required by operators. Utilities are reviewing existing infrastructure and incorporating projections for climate impacts into plans for new infrastructure.

A common risk for thermal and large hydro generation is water [13] [14] [15]. Climate change increases variability in the availability of the quantity and quality of water required in electricity generation. Hydro power output has declined due to climate change in Chile [16] and California, suffering its worst drought in 1,200 years [17]. Competition for water supply will increasing if efficiency does not match rising demand from households and cities, agriculture and industry because of rising population and prosperity. In some areas absolute shortages may increase.

An adaptation solution gaining ground in places such as Chile and California is switching to low-water generation technologies, such as solar and wind. The scale of adaptation will vary markedly with local conditions. New York State, for example, is restructuring the electricity system around microgrids and distributed energy resources to increase resilience and reduce costs, partly in response to the damage and losses caused by Hurricane Sandy in 2012 [18]

To maintain electricity supply reliability despite the growing challenges posed by climate change it is necessary to undertake remedial adaptation work on power systems. Without corresponding improvements in efficiency the additional cost will raise charges for consumers

Mitigation and adaptation policy and investment have been increasing because of rising awareness and deepening concerns about intensifying impacts of climate change. The non-trivial external costs, other than climate change, of fossil fuels are also being more clearly quantified [19]. Effectiveness will in part depend on accurate pricing of energy, incorporating all cost not just the benefits.

Pricing of carbon and other pollutants introduces information, hitherto missing from energy prices, to redress distortions and improve market efficiency, regulatory efficacy and capital allocation. Prices incorporating more information send better signals raising prospects for improving the quality of public and private sector decisions affecting resource scale, allocation and efficiency. The movement to price pollution and improve the quality of energy prices, for example carbon pricing and pollution taxes, will continue because benefits are widely recognized by international institutions and increasingly accepted by governments.

Appendix 2: Macroeconomic effects of fixed-cost renewable energy

Costs for wind, solar and hydro are usually fixed whereas for fossil fuels costs are variable. The transition from fossil fuels to renewable energy is therefore also a transition from variable to fixed costs for an important factor of production, assuming most transportation and heat is also electrified as necessary to temper climate change. Greater macroeconomic stability might follow if fixed costs for energy are preferable to unpredictable variability.

To explore the effect consider two countries, Green and Grey, alike in all respects except that energy costs for the former are fixed and variable for the latter. Assume that the effects of fixed or variable costs embedded in products received via trade do not have much effect because of substitution.

In Grey, many people believe the ups and downs of energy costs affect the fortunes of the economy, at least in the short run, which weighs on sentiment and behaviour. Transportation is particularly sensitive because oil prices are volatile [20]. In the long run, production-factor substitution and technological innovation reduce energy intensity moderating the impact of energy costs. That said efficiency faces social and technical limits while production costs rise as finite energy stocks dwindle. The picture is more uncertain in a world of countries similar to Grey. Some are well endowed with energy stocks of variable quality and declining quantity while others depend on imports.

In Green, people focus more time on realizing their goals and potential because energy costs are stable, encouraging long-term planning and investment, including energy efficiency, because paybacks are certain. The constant flow of energy at a steady rate is not an impediment for the economy or the satisfaction of needs because human ingenuity is a deep resource far from exhaustion. Efficiency reaches an optimum at lower cost over the long-term because energy-cost stability provides clearer returns to focus innovation. In a world of Grey, Green, despite exposure through trade, is an island of relative macroeconomic stability.

As a simple model the world of Green and Grey draws attention to the central role energy plays in the economy. Green is more attractive than Grey, offering a vision for national ambitions to pursue because in the short-run history shows variable energy costs have been troublesome.

When global expenditure on energy peaked as a fraction of GDP in 1980 and 2008 net power available reached lows and the economy was sluggish or in recession, whereas the converse was true in 1998 when growth was strong [21]. Macroeconomic sensitivity to energy-price shocks is also not constant, evolving over time with development status, economic structure, energy mix, and energy trade balance [22]. For example rising the use of oil has at times increased consumers exposure to volatility associated with market speculation and inadequate market data [20].

Historically, however, long-run energy cost-to-income ratios have been quite stable with steadily improving quality and productivity of energy [23]. The reasons lie in resource switching, factor substitution, innovation and efficiency. Declining resource quality is offset by technical improvements to the quality of consumption increasing efficiency [24], moderating sensitivity of households, firms and governments alike to upside volatility in energy prices.

That is cold comfort to consumers and policy makers buffeted by unexpected upswings in energy prices beyond their control and foresight. When factor prices, such as energy, diverge in the short-run from expectations budgets are disrupted yet long-run commitments must honoured. Such experience colours perceptions and behaviour through subsequent cycles. Hence, despite long-run trends energy prices in the short-run are a worry for consumers.

Energy will remain a source of uncertainty where the flow of fossil fuels is determined by competing interests of many parties seeking to maximize private advantage. While improving efficiency gives hope for less volatility it is hard to be sanguine about the outlook. Resource quality is declining and the scale of some projects, which has reduced prices for coal, may not add up when demand from major importers peaks. Demand for coal in China appears to be peaking and imports are falling with downward pressure expected to intensify [25] [26]. Fossil fuel subsidy cuts are proposed [27] as ambitions to reduce emissions grow [28]. Meanwhile, concerns persist over the financial footing of unconventional oil production in the United States [29] while conventional oil exporters may yet regroup to coordinate output limits despite recent disarray.

Switching to fixed-price renewable energy would eliminate the problem, more so for peripheral economies dependent on fossil-fuel imports. What might be the consequences of a society powered entirely by renewable energy? So far most attention has focused on the process of transition rather than the end result. Studies identify multiple benefits, including greater prosperity, more jobs, and better health, plus of course avoiding a great deal of damage that would otherwise accumulate because of climate change. The benefits of energy transition are expected to equal if not exceed the costs [30] [31] [32]. After transition is complete society benefits of clean-energy resources will continue to flow and may be complemented by greater macroeconomic stability if indeed fixed costs have that effect.

Few if any countries today depend almost entirely on steady prices of renewable energy. Bhutan, Costa Rica, Lesotho and Paraguay obtain almost all their electricity from large hydro. Transportation and heat are not yet electrified. Iceland uses geothermal and large hydro for almost all its electricity and heating needs. Others, such as Sri Lanka and Sweden, have ambitious plans to fully decarbonize by the 2030s.

Uruguay may be the closest analogue for Green. Biomass, hydro, solar and wind generate 95 per cent of electricity and account for 55 per cent of overall energy consumption. Stable and clear policy offering tariffs of 6.4 ¢/kWh and 8.7 ¢/kWh respectively [33] attracted foreign investors accelerating wind and solar deployment. Increasing use of wind and solar over the last three years has coincided with electricity costs falling 30 per cent. A growing role for wind and solar in the energy mix has been accompanied by more stable power supply, compensating for variations in large hydro output, and resulted in a surplus turning the country from electricity importer to exporter. [34].

Whether any conclusions about the impact of fixed-price renewable energy on macroeconomic stability may be drawn from comparing these countries with analogues mostly using fossil fuels is a matter to be taken up elsewhere. It may be too early to say given that few countries have gone as far as Uruguay and are not special cases in terms of economic structure and resource endowments. Coincidentally, Iceland, Costa Rica and Uruguay rank high or very high on the human development index, Bhutan and Paraguay medium, and Lesotho low.

The point of this conjecture is simply to illuminate the novelty of wind and solar and the potentially profound effects on economic development. The consequences, if any, will become clearer as the energy transition advances such that wind and solar come to dominate energy consumption, including transportation and heat, in at least a few economies. The implication for Cambodia is that increasing use of solar and wind and a leapfrog to early electrification of transportation, such as electric buses and motorcycles, and heat may be positive for economic resilience, prosperity and equity, as well as public health and well-being.

Appendix 3: Opportunities for leapfrogging to 100% renewable energy

How much wind, solar and small hydro, plus perhaps biomass, should Cambodia plan to incorporate in the energy mix for electricity generation and by when? The future is probably close to 100 per cent but when depends on values, vision, policy, and perceptions of risk and net benefits. So the question becomes one of mapping a pathway back from that future destination to the present situation without undue risk or cost while recognizing all the consequences and trade-offs of various options.

Numerous studies have concluded electricity systems mostly or entirely powered by wind, water and solar are feasible and cost effective [11] [35] [12] [10] [36] [37] [38] [39] [40] [41] [42] [30]. Examples of recent projects [43] [44] [45] plus levellized cost estimates for renewable energy [46] and storage [47] demonstrate economic viability across increasingly diverse situations despite explicit and implicit subsidies benefitting fossil fuels and distorting markets. Strong learning rates and other returns to scale will continue to drive down the costs of wind, solar and storage squeezing conventional assets further to the right of the merit order.

From vision to pathway for an energy leapfrog

Technology trends, energy risks, and global climate policy provide a framework for policy makers to craft a credible and robust vision for a renewable-energy future. From that vision mapping a path back to the present provides a guide for policy and plans integrating energy efficiency and renewable energy to for an early transition to the benefits of a low-carbon low-risk high-opportunity pathway.

Refocusing policy to prioritize renewable energy holds potential for a development leapfrog jumping over the high-carbon pathway most countries have taken. Cambodia could avoid the costs and risks associated with high-carbon legacy infrastructure currently weighing down many countries. Sunk costs, path dependence and behavioural inertia colour expectations and policy, restricting opportunities and increasing risk.

By switching to a pathway aiming to develop an economy powered by low-carbon, low-water energy Cambodia would positively align with trends in technology which are reducing cost, improving performance, and increasing flexibility. Cambodia is positioned to take a shortcut through the energy transition, one not available to neighbours and competitors with a legacy of high-carbon infrastructure. Moreover, Cambodia can capitalize on the scale economies of innovation and deployment in places such as Australia, China and the United States.

Policy principles for an energy leapfrog

Concepts, policies, approaches are highly contextual because the renewable energy resource endowment varies with latitude and geography and character of legacy energy systems. What might be an effective energy transition strategy for a country on a high-carbon pathway may not be appropriate for a country like Cambodia with limited carbon dependence.

Risk and planning challenges turn into opportunities if legacy principles, norms and assumptions are reconsidered for correspondence novel technological and environmental conditions now taking hold. Three forces have emerged which must be incorporated into policy for an energy leapfrog:

1. The sustainability imperative
2. The power of technological learning rates
3. The flexibility of modular systems

A combination of carbon price, feed-in-tariffs, technology support and regulation appears is usually thought to offer the most cost-effective approach to overcoming inertia and accelerating low-carbon diffusion and reductions in emissions [48]. However, in Chile directing funds into expanding zero-carbon generation and sectorial emissions caps deliver greater reductions at less cost to society than a carbon tax on the economy and emissions [49]. Ambitious goals are also valuable for stimulating investment, driving diffusion and reaping benefits early [50]. Successful energy transitions are shaped by policy and innovation efforts which are persistent, continuous, aligned and balanced [7].

A systemic view integrating technology with context, energy production and consumption is essential to manage risk, identify synergies and maximize benefits for prosperity, well-being and resilience. In practical terms, policy and regulation prioritize energy efficiency, solar modules, solar thermal, small hydro, and wind turbines, plus advanced battery storage. Risks largely lie in integrating relatively new technologies in somewhat novel configurations and concurrently tackles the challenge of sequencing deployment in ways which maximize value of legacy assets and exploit declining prices exhibited by solar, wind and storage. Over time with experience risks will fall and performance improve.

Integration of wind, and solar, at large-scale into the power system does present challenges. Output is variable while the legacy power system was designed for the controlled output of conventional resources. The problem is treatable by redesigning and optimizing the power system to match the characteristics of wind and solar [38]. A combination of network planning, efficient and complementary siting of wind and solar projects, advanced storage, demand response and smart systems overcomes the variability challenge [41].

Not all surplus output need be redirected to stationary storage. Electric buses are already competitive and cars will be by the early 2020s if not sooner even with low oil prices. China switched to electric motorcycles over a decade ago. Capital cost is similar to four-stroke motorcycles common throughout Cambodia. Cooling and heating services can also be designed to soak up surplus electricity.

Microgrids and accelerated sustainable electrification

A pathway producing a leapfrog reconsiders deployment, leveraging the modular form of many renewable-energy technologies to deliver incremental electrification. For example, microgrids powered by solar and storage do not necessarily have to provide around-the-clock service initially. Instead, the system expands by adding additional solar and storage modules as budgets become available, such as through tariffs plus local and national funds. In that way the system evolves with local needs and capabilities towards constant service.

Microgrids become the key nodes in the power system. If necessary microgrids may interconnect forming regional cellular networks integrating meso-scale loads and assets if necessary. The power system grows organically from the base-up avoiding the fragility, costs and lags of conventional systems built from the top-down radiating out from central power plants. Such an approach is superior in speed, scale and security accelerating access to sustainable, resilient and affordable electricity.

A new model is emerging which is base-up rather than top-down, embedding energy efficiency in design, service and consumer co-production focused around distributed generation and storage. The new model, positively aligned to dynamics and impacts of technology and climate, is flexible and adaptable, evolving with developments in costs and performance.

Leapfrog

Technology, systems and principles for a leapfrog to clean energy are available. Systematic deployment in Cambodia requires long-term planning plus capital and capabilities. Capital will flow if policy and regulation are clear, simple and stable, putting in place a coherent framework for planning and investment. Capabilities can be nurtured with local and international resources and collaboration. It is critical therefore to develop a coherent vision for a low-carton Cambodia and by mapping back a pathway to today design policy and regulation to accelerate transition and realize early returns in benefits for the prosperity, well-being and resilience.

Opportunity	Sustainable Energy Zone (SNZ)
Description	Pilot districts integrating high energy efficiency and renewable energy
Benefits	Rapid increase in clean electricity, improving health and well-being, stimulating local economy multiplier, creating jobs and reducing poverty
Output/result/impact	Rapid increase in competitive and reliable clean electricity
Outcome	Better quality of life and more economic opportunity from expanded access to modern energy services
Enabling actions	Develop institutions, regulation, technical and vocational capabilities
Rationale	1. Pilot districts provide learning-by-doing, seeing-is-believing platforms 2. Inspire policy makers, investors and communities to replicate and scale an integrated approach enabling consumers to derive greater service from each unit of renewable energy because of higher energy efficiency
Resources	• Multilateral agencies • Bilateral agencies • Private: social impact funds, commercial lenders, developers

Opportunity	Energy Efficiency Finance Fund (E2F2)
Description	Revolving loan funds at low or zero interest rate for commercial and industrial energy efficiency design and retrofit
Benefits	Increases Cambodia's attractiveness for investment by tackling investor concerns about electricity costs, while also creating more jobs and skills in the nascent energy-service company (ESCO) sector
Output/result/impact	Increased energy efficiency of commercial and industrial (C&I) production
Outcome	Commercial and industrial consumers international competitiveness improves because they can obtain more value from each unit of electricity, which may also help secure jobs and improve Cambodia's investment reputation
Enabling actions	Survey C&I energy efficiency, identify needs, determine fund size and terms, evaluate local ESCO capabilities, support technical and vocational training, enhance efficiency regulation

Rationale	1. Investors have expressed concerns about the cost of electricity, which rightly is unsubsidized, relative to Cambodia's competitors 2. Rather than lower price it is more effective and sustainable to improve consumption efficiency at the initial design stage, optimizing processes and layout, and shallow and deep retrofits for existing facilities 3. Grants and low-cost finance is warranted because the benefits extend beyond the host to the economy in general and to build confidence among C&I investors, who frequently have limited understanding of the impact of energy efficiency and rapid payback 4. Stimulating demand may lay the foundations for C&I energy efficiency to emerge as a mainstream self-sustaining industry funded by commercial bank loans
Resources	• Multilateral agencies • Bilateral agencies • Private: social impact funds, commercial lenders, developers, ESCOs

Opportunity	**Million Partners for Energy Security and Equity (MPESE)**
Description	Solar on every rooftop, storage in every neighbourhood, integrated into community microgrids and regional cellular mesogrids
Benefits	Expand scalable access to affordable clean electricity for households and businesses in ways which maximize asset utilization and efficiency
Output/result/impact	Community and regional power systems integrating solar, storage, wind, small hydro, biomass assets in co-production business models incorporating households and communities as equity partners, informed by lessons and insights from SNZs
Outcome	Establishes architecture and process for scalable, flexible, sustainable and resilient future-proof power systems supporting local economic development, creating jobs and strengthening rural and regional social stability
Enabling actions	Develop institutions, regulation, co-production business models, technical and vocational capabilities
Rationale	1. Increase residential and non-residential consumer participation in energy supply and security through co-production models nurturing collaboration and cohesion

Rationale (continued)	2. Establish mechanisms to accelerate efficient incorporation of rooftops and other marginal space into clean energy production for energy security 3. Open channels for resident households and developers to share in the returns of community power systems 4. Facilitate scaling of power supply to meet nascent commercial and industrial needs 5. Strengthen resilience of energy supply to climate change impacts
Resources	• Multilateral agencies • Bilateral agencies • Private: NGOs, social impact funds, commercial lenders, developers

Opportunity	**Energy Transition Pathway Policy (ETP2)**
Description	In-depth study and mapping of policies integrated and sequenced to establish a stable pathway to accelerate renewable-energy and energy-efficiency diffusion and investment
Benefits	Enable Cambodia to realize early benefits from energy transition for economy, prosperity, competitiveness, jobs, public health and environmental quality
Output/result/impact	Clear and coherent long-term policy package coordinating regulation, technology diffusion, and public and private investment, plus integrating SNZ, EF2 and MPESE opportunities
Outcome	Strong framework building confidence among all stakeholders, including policy makers, civil servants, investors and citizens, in the feasibility and benefits of early energy transition
Enabling actions	Review resources and technologies, estimate costs over time, identify regulatory cost reduction potential, learn from vanguard countries worldwide, solicit views and insights from stakeholders, establish policy framework, develop policies, identify and leverage synergies, review and refine pathway
Rationale	1. Energy transition is complex 2. Long-term policy pathway maximises opportunities, minimises risks, builds confidence, facilitates economies of scale
Resources	• Multilateral agencies • Bilateral agencies • Private: foundations and philanthropies

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Executive Summary

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