Renewable Energy 89 (2016) 422–436

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Rural electrification in India: Galilee Basin coal versus decentralised renewable energy micro grids

Lynette Molyneaux [a,*], Liam Wagner [b], John Foster [a]

[a] Energy Economics and Management Group, University of Queensland, Brisbane, Australia
[b] Economics, Griffith Business School, Griffith University, Brisbane, Australia

ARTICLE INFO

Article history:
Received 25 June 2015
Received in revised form
9 November 2015
Accepted 3 December 2015
Available online xxx

JEL Classification:
Q42
Q53
R51

Keywords:
Rural electrification
Renewable energy
Distributed energy

ABSTRACT

The state of Bihar in India has approximately 75 million people with no access to electricity. The government of India has pursued a policy of rural electrification through the provision of centralised coal-fired power which has been unable to resolve the low levels of electrification. Coal supply woes in India have led Indian companies to pursue new coal mines in Australia's Galilee Basin. The costs of these mining ventures will be high due to the mining infrastructure required and long transport distances to rural India. A high level analysis of mining, transport and power station investment to meet rural demand in Bihar shows that the absolute investment requirement using coal, especially coal sourced from Australia, as an expensive option. Pursuing electrification through village level, renewable energy micro-systems provides more flexibility. Pollution costs associated with coal-fired generation, employment benefits associated with many village implementations and a rural load unsupported by industry load, show a benefit associated with decentralised, renewable energy electrification.

1. Introduction

> "Advancing social and economic progress with clean energy is the role of leaders globally. India is a prime example of a nation exerting its right to grow and creating energy access for all of its citizens. Clean energy from coal is a major part of the solution and will be essential to achieving that goal" [73].

Coal is credited with powering the industrial revolution but evidence that coal improves emissions and achieves environmental goals is scant. Certainly the industrial revolution improved quality of life for the middle and upper classes, but conditions for the working poor who moved to the towns in search of work were abysmal. For the urban poor it meant pollution, urban squalor and illness. A government report from the 1840's noted that the smoke in Manchester had "risen to an intolerable pitch, and is annually increasing, the air is rendered visibly impure …" [32]; P81). The life expectancy of a rural working person in England was 38 years, whilst that in Manchester was 17 years, due to more than 57% of children dying before they turned five. The recruitment drive for the Crimean War rejected 42% of the urban recruits because of bronchial diseases and rickets [32].

Decades later China deployed coal to fuel development but the health implications for the Chinese have been severe. The drag on the economy from airborne pollution is estimated to have decreased consumption and resulted in welfare loss of between 5 and 14% to the Chinese economy [65]. China's Health Minister from 2007 to 2013, a professor of medicine and molecular biologist, has stated that lung cancer is now the leading cause of death in China and that annually 350,000 to 500,000 people die prematurely as a result of pollution. Consequently, China is preparing to spend US$278 billion over 5 years in an attempt to control pollution [19].

An estimated 400 million people living in 80 million households in India have no access to electricity. India also seeks to use coal for development. In particular the populous state of Bihar, with 84% of households lacking access to electrification provides a good case study. Indian power companies are not able to source enough coal domestically for rural electrification, causing them to look to international sources. Adani, an Indian company, has invested in a mining venture in the Galilee Basin in Australia, which does not have easy access to markets.

* Corresponding author.
E-mail addresses: l.molyneaux@uq.edu.au (L. Molyneaux), l.wagner@griffith.edu.au (L. Wagner), j.foster@uq.edu.au (J. Foster).

http://dx.doi.org/10.1016/j.renene.2015.12.002
0960-1481/

This paper looks at the costs associated with a large mine development, multiple coal transportation systems, a fleet of coal-fired power stations and the network infrastructure required to distribute power to those without access to electricity in Bihar, India. It compares this with the costs of decentralised, renewable energy micro-grid systems to ascertain which option provides the greater benefit. The methods are outlined in Section 2, and the results in Section 3 with Section 4 providing discussion around the results. Section 5 concludes.

2. Methods

The analysis uses an unconventional approach to comparing electrification options but not a complicated methodology. It seeks to compare the investment costs required to build infrastructure that will fuel large, centralised power stations and networks in rural India with the costs of building decentralised micro-grids using locally sourced renewable energy. Comparisons are based on potential investments required and levelised cost of energy provision. Data including: the mine investment; transportation investments; power station investment and operational costs; network infrastructure investment, renewable energy potential and demographics are all sourced from public sources as detailed in the tables and the notes to the tables in the article.

With China in the throes of counting the costs associated with coal pollution, evidence from China is used as a benchmark to estimate the costs that may be experienced by India pursuing the same course.

2.1. Comparing options using levelised cost

Levelised cost over the life of the projects is used to compare the different options for Bihar because it allows for comparison between varying costs and levels of production over different technical lifetimes. The methodology ensures that investment and operating costs are discounted over varying lifetimes to their present values. Capital-intensive technologies are very sensitive to discount rates which means that the risk profile of projects need to be reflected in the discount rate. To calculate a discount rate relevant to the risk profile of these projects, the Weighted Average Cost of Capital (WACC) is calculated using a model based on Capital Asset Pricing Model (CAPM) theory. The WACC estimates the rate that a company is expected to pay on average to all its security holders to finance its investments.

2.1.1. Calculation of WACC

The WACC is calculated by estimating the effects of inflation, taxation, risk free rates of return, cost of equity risk premium, cost of debt risk premium, asset price risk and corporate debt to equity ratios for operations in Australia as well as in India on the discount rate. The variables listed in Table 1 are used in the calculation of WACC and LCOE.

2.1.1.1. Inflation pass through rates. The pass through rates (ρ) for inflation are set at $\rho_r = 0.75$ for revenue streams and $\rho_c = 100\%$ for cost streams for non-financial operating assets. The prevailing inflation rates (CPI) for Australia and India have been sourced from the national reserve banks' base target inflation rates i.e. 2.5% and 5.7% respectively. The pass through rates are applied onto the cost and revenue streams such that in year t,

Table 1
Variables involved in calculation of WACC and LCOE.

Component	Symbol	Australia	India
Liabilities	L	100%	100%
Debt	D	60%	60%
Equity	E	40%	40%
Risk free Rate of return (RoR)	RoR	3.72%	7.70%
Market risk premium		6%	9.05%
Market RoR		9.72%	16.75%
Corporate tax rate		30.0%	33.99%
Effective tax rate	T	22.5%	18.50%
Debt basis point Premium		2.95%	3.30%
Cost of debt	R_d	6.67%	11%
Gamma	Γ	0.5	0.5
Asset Beta	β_a	0.8	0.86
Debt beta	β_d	0.06	−0.497
Equity Beta	β_e	1.6	1.91
Required return on equity CAPM	R_e	13.33%	25.37
Inflation	CPI	2.50%	5.7%
WACC Post-Tax nominal		7.76%	14.49%
WACC Post-Tax real		5.13%	8.32%

$$CPI(t)_R = \{[1 + (CPI/100)]^*\rho_R\}^t,\ CPI(t)_C = \{[1 + (CPI/100)]^*\rho_C\}^t \quad (1)$$

2.1.1.2. Taxation. The corporate tax rate in Australia is set at 30% [60], and following the application of deductible items such as interest payments and imputation credits, the effective tax rate is assumed to fall to 22.5% [86]. The prevailing taxation rate for companies in India is currently 33.99% [60]. Interest payments and the like are allowable deductible items, however the minimum tax rate allowable under Indian corporate tax law is set at 18.5% [13].

2.1.1.3. Risk free rate of return. The risk free Rate of Return (RoR) has been calculated by taking the previous 20 day average of the 10 year government bond rates (Australia 3.72% and India 7.7%) [14].

2.1.1.4. Equity risk premium. The equity risk premium is central to establishing the required rates of return to establish the WACC [22] and its use in the CAPM. For the Australian assets a benchmark 6% is used for the equity risk premium [78]. With the Indian assets (specifically electricity generation options), the equity risk premium is derived from first principles. While India is an emerging economy, it has a very mature equity market [20]. The methodology as proposed by Ref. [22] is used to calculate the required equity premium. As of March 2015 the country credit/risk rating for India is BBB [80] and the credit default swap premium of 3.5%. The scaled equity risk premium is 9.25% and the required market rate of return is 16.95%.

2.1.1.5. Debt risk premium. The debt basis point premium for the coal mine in Australian has been estimated at 295 basis points, via the standard regulatory agency guidelines for BBB + rated corporate lending requirements [80]. The electricity generation asset premium in India has been derived from the prevailing 330 basis point from the prevailing country risk premium [22]. The cost of debt (R_d), for the Australian and Indian operations, is derived as 6.67% and 11% respectively.

2.1.1.6. Asset risk. The asset Gamma (Γ), equity beta (β_a) and the debt beta (β_d), for the Adani operations in Australia have been sourced from the Queensland Competition Authority (QCA) as is the standard practice for assessing these types of projects [78]. The