



Economic analysis of a small-sized combined heat and power plant using forest biomass in the Republic of Korea

Yeongwan Seo, Han-Sup Han, Edward M. (Ted) Bilek, Jungkee Choi, Dusong Cha & Jungsoo Lee

To cite this article: Yeongwan Seo, Han-Sup Han, Edward M. (Ted) Bilek, Jungkee Choi, Dusong Cha & Jungsoo Lee (2017) Economic analysis of a small-sized combined heat and power plant using forest biomass in the Republic of Korea, Forest Science and Technology, 13:3, 116-125, DOI: [10.1080/21580103.2017.1350209](https://doi.org/10.1080/21580103.2017.1350209)

To link to this article: <http://dx.doi.org/10.1080/21580103.2017.1350209>



© 2017 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



Published online: 05 Sep 2017.



Submit your article to this journal [↗](#)



View related articles [↗](#)



View Crossmark data [↗](#)



Economic analysis of a small-sized combined heat and power plant using forest biomass in the Republic of Korea

Yeongwan Seo^a, Han-Sup Han^b, Edward M. (Ted) Bilek^c, Jungkee Choi^d, Dusong Cha^d and Jungsoo Lee^d

^aInstitute of Forest Science, Kangwon National University, Chuncheon 200-701, Republic of Korea; ^bDepartment of Forestry and Wildland Resources, Humboldt State University, 1 Harpst Street, Arcata, CA 95521-8299, USA; ^cUSDA Forest Service, Forest Products Laboratory, Madison, WI 53726-2398, USA; ^dDepartment of Forest Management, College of Forest and Environmental Sciences, Kangwon National University, Chuncheon 200-701, Republic of Korea

ABSTRACT

Economic analysis was conducted on the feasibility of operating a small-sized (500kW/hour) gasification power plant producing heat and electricity in a rural town surrounded by forests in the Republic of Korea. Cost factors that were considered over the plant's 20-year life included wood procurement, a wood grab loader, a chipper, a chip dryer, a gasifier, a generator, land and building, wages, and office management. All the cost factors were calculated based on the 2016 market values for logs, information from machine manufacturers, and a literature review. Revenues were estimated from selling heat and electricity using the 2016 average prices that were sourced from Korea District Heating Corporation and Korea Power Exchange, respectively. Using a spreadsheet program, cash flows for costs and revenues were arranged to calculate net present value, internal rate of return, and payback period of the plant. Also, sensitivity analyses were performed on the cost of wood procurement and revenues from selling heat and electricity, which were the most significant factors affecting the economic feasibility. The results, as reinforced by the sensitivity analysis, suggest an investment in the small-sized gasification power plant may be attractive from a financial standpoint, especially if the owners are in a position to get additional revenue from heat sales and to take advantage of Renewable Energy Credits.

ARTICLE HISTORY

Received 24 March 2017
Accepted 29 June 2017

KEYWORDS

Biomass conversion; biomass energy; combined heat and power plant; renewable energy; sensitivity analysis

Introduction

The Republic of Korea (Korea) imports 96% of the energy it consumes from other countries, and renewable energy such as bioenergy and hydropower represented only 4.6% of the country's total primary energy in 2015 (Korea Energy Agency 2016). In 2008 the government announced the "Third National Energy Master Plan" to induce industrialization of renewable energy in the country with a goal of supplying 11% of the total energy demand from renewable resources by 2020 (Korea Presidential Committee on Green Growth 2009).

To support the plan, the government began enforcing "Renewable Portfolio Standards (RPS)" in 2012, by which a utility company supplying over 500 MW per hour of electricity must produce at least 2% of its total electricity supply using renewable energy sources. Also, renewable energy certificates (REC), which can be traded in the market, were introduced to support the RPS policy (Korea Energy Agency 2012). The number of REC traders increased from 5957 in 2014 to 12,458 in 2015, and to 16,890 in 2016 (Korea Power Exchange 2017).

Meanwhile, forest biomass is recognized as one of Korea's major renewable energy resources, being available in almost all rural regions of the country. The forest area is 6370 thousand hectares, which represents 63.6% of the country's total land area. The potential amount of forest biomass that could be supplied through commercial or non-commercial harvest was estimated to reach about 1.3 million tons per year (Korea Forest Research Institute 2014).

With the rich forest biomass resources, efforts have been focused on development of diverse forest biomass conversion

technologies (Ince et al. 2011), one of which is a small-sized combined heat and power generator using a gasification process that was developed in Korea (Choi et al. 2005; Lee 2009; Seo 2013). This effort was hoped to be especially promising for rural areas surrounded by forests in which electricity for heating and cooking is produced from non-renewable resources such as coal and gas, and is supplied from other areas. If electric power and heat energy were produced using the locally-supplied forest biomass, then heating and cooking costs would potentially be less than if the energy is sourced from other areas.

Economic analysis is a good tool for a potential owner of a small gasification power plant to evaluate the plant's potential economic performance and to identify variables critical to its success. Therefore, the objectives of the study were: (i) to analyze the economic feasibility of installing and operating a small-sized combined heat and power generator (500 kW/hour) using forest biomass; (ii) to provide basic data that can be used to assess the potential of biomass energy supply for mountain villages in Korea; and (iii) to create a flexible and powerful spreadsheet-based model that analysts could use to insert their own assumptions to do a preliminary financial feasibility analysis of a small-scale combined heat and power generator.

Method

Overview of economic analysis

A generation system capable of producing 500kW per hour of electricity was developed by Samyang Eco-energy Co in

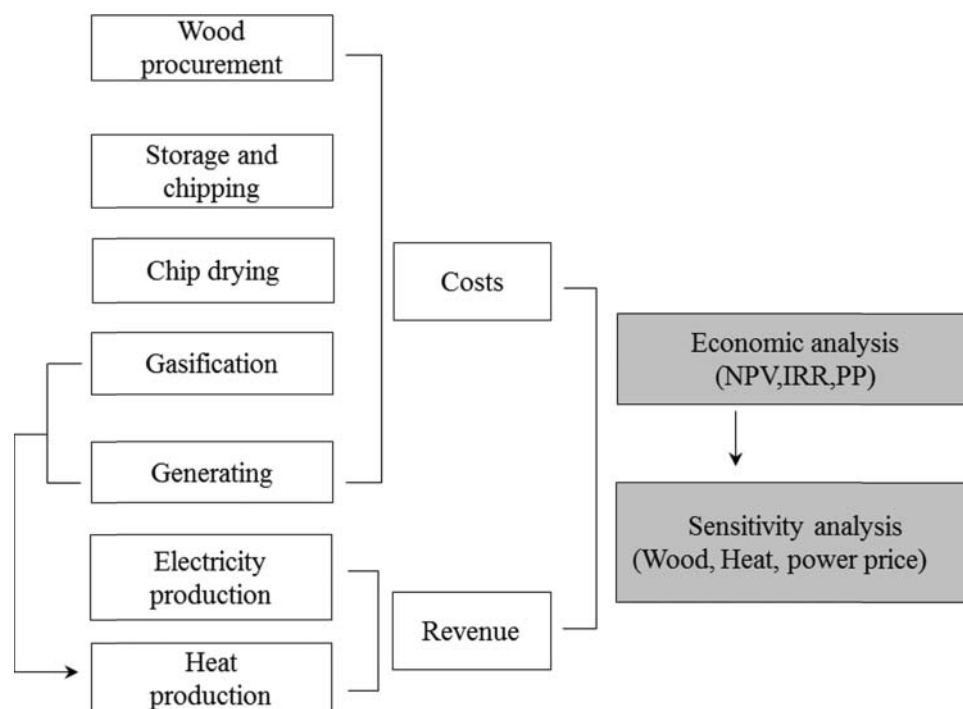


Figure 1. Process and cost factors of a small-sized (500 kW/hour) gasification power plant.

Korea. An installation of this power plant in a rural town was hypothesized and its major cost factors: wood procurement; storing and chipping; chip drying; gasification; and electricity generation were incorporated into an economic analysis. Costs incurred at each stage of the process were estimated and applied to the analysis. Added in the cost analysis were expenses for ancillary facilities, finance, and operation as showed in Figure 1. Selling prices of electric power and heat produced from the process were used as revenue. All costs and selling revenues were sourced from 2016 market prices, information from machine manufacturers, and a literature review.

Each piece of equipment needing replacement over the 20-year planning period was replaced at the end of its operating life at its original cost plus inflation. At the end of the planning period, equipment book values based on straight-line depreciation were used for terminal valuations.

Net present value (NPV), internal rate of return (IRR), and payback period (PP) were calculated based over a 20-year cycle, which was the generator's estimated life. Sensitivity analyses were also conducted for the cost of forest biomass procurement and selling prices of electric power and heat. Our generic models were prepared in a Microsoft®Office (Redmond, WA) Excel workbook file.

Investment cost analysis

The cost analysis includes two major parts: cost incurred from the energy production process; and supporting cost items and revenues from selling heat and electricity. We hypothesized installation of this power plant in a rural town that could be supplied with forest biomass from nearby mountains. We assumed that all the power and heat produced from the plant would be sold to the residents in the rural town. Table 1 summarizes investment costs at every stage of the process and details are as follows.

Forest biomass procurement

Forest biomass procurement cost was determined based on a final consumer price for logs in 2016 (Korea Forestry Promotion Institute 2016) and assumed to include costs for felling, processing, yard, and transportation of logs.

Storage and chipping

Logs are moved to a wood depot and chipped after purchasing them. Wood grab loader and chipping machine costs were included for moving and chipping the materials. Their operating costs were classified into fuel costs, and maintenance and repair expenses. The latter were assumed to be 50% of their depreciation costs (Brinker et al. 1989). These operating costs were assumed to increase by 5% per year. These machines were assumed to have 10-year operating lives.

Wood chip drying

Maintenance and repair expense of a dryer was assumed to be 1% of the purchase and increase by 5% per year, but its fuel cost was assumed to be zero as 40% of its heat production is self-consumed for drying. The dryer was assumed to have a 10-year operating life.

Gasifier

Annual maintenance and repair expense of a gasifier was assumed to be 1% of the purchase and increase by 5% per year, but its fuel cost to be zero as 10% of electric power production is self-consumed for operating over its 20-year life.

Generator

Annual maintenance and repair expense of a generator was assumed to be 4% of the purchase and increase by 5% per year, but its fuel cost to be zero as gas produced from a generator is used for its operating. The generator was assumed to have a 7-year operating life.

Table 1. Model parameters and input data that were used to perform the economic analysis of a small-sized (500 kW/hour) combined heat and power plant in Korea.

Cost parameters	Unit	Values used	Note
Forest biomass			
Procurement	1000 won/ton	76	
Demand	ton/year	6205	20 ton/day, 85 of utilization
Wood grab loader			
Procurement	1000 won	54,000	
Life	year	10	
Salvage value	1000 won	1000	
Depreciation	1000 won/ton	5300	(purchase-scrap value)/life(10 years)
Maintenance and repair	1000 won/ton	2650	50 of depreciation, increasing rate 5/year
Fuel	1000 won/ton	6329	
Chipper			
Procurement	1000 won	258,500	
Life	year	10	
Salvage value	1000 won	1000	
Depreciation	1000 won/ton	25,750	(purchase-scrap value)/life(10 years)
Maintenance and repair	1000 won/ton	12,875	50 of depreciation, increasing rate 5/year
Fuel	1000 won/ton	12,658	
Dryer			
Procurement	1000 won	100,000	
Life	year	10	
Salvage value	1000 won	1000	
Depreciation	1000 won/ton	9900	(purchase-scrap value)/life(10 years)
Maintenance and repair	1000 won/ton	1000	1 of procurement, increasing rate 5/year
Fuel	1000 won/ton	0	use 40 of heat production for fuel
Gasifier			
Procurement	1000 won	150,000	
Life	year	20	
Salvage value	1000 won	1000	
Depreciation	1000 won/ton	7000	(purchase-scrap value)/life(20 years)
Maintenance and repair	1000 won/ton	1500	1 of procurement, increasing rate 5/year
Fuel	1000 won/ton	0	use 40 of heat production for fuel
Generator			
Procurement	1000 won	500,000	
Life	year	7	
Salvage value	1000 won	1000	
Depreciation	1000 won/ton	71,286	(purchase-scrap value)/life(5 years)
Maintenance and repair	1000 won/ton	20,000	1 of procurement, increasing rate 5/year
Fuel	1000 won/ton	0	use 10 of power production for fuel
Land and construction			
Land purchase	1000 won	500,000	2500 m ³ area
Construction	1000 won	32,000	
Maintenance and repair	1000 won/year	320	1 of construction, increasing rate 5/year
Labor and office management			
Moving and chipping	1000 won/person/year	30,000	1 person
Operating power plant	1000 won/person/year	24,000	2 people in 3 shifts
Administration	1000 won/person/year	21,600	1 person
Insurance	1000 won/year	4200	
Miscellaneous	1000 won/year	4200	water and electricity charge
Financing			
New loan principal	1000 won	1,500,000	
Bank financing charge	1000 won	7500	paid at loan initiation
Loan interest rate	percent/year	6.00	fixed for 10 year
Loan principal repayment	1000 won/year	150,000	10 year redemption
Tax			
National tax	If income ≤ 0.2 billion won, then national tax is 10		
	If 0.2 billion won < income ≤ 2 billion won, then national tax is 20		
Local tax	If income ≤ 0.2 billion won, then local tax is 1		
	If 0.2 billion won < income ≤ 2 billion won, then local tax is 2		

Land and construction

Land area for the plant was 2500 m² in the study and construction cost was for the whole facility of the plant and included costs for office, access road, fence, and pavement work. Annual maintenance and repair expense was assumed to be 1% of the construction cost and increase by 5% per year. Land is not depreciable under South Korean tax law. The terminal value of the land was its original cost plus inflation. The buildings were depreciated over 20 years using straight line depreciation. It was assumed that the plant and office would have no residual value at the end of the 20-year project life.

Labor and office management

Labor cost (i.e., wages and benefits) was based on eight full-time workers (8 hours per day), including one for moving

and chipping logs, one for management and administration, and six for power plant operation with a three shift system. Also, insurance expense was applied at 0.4% of the facility cost. Other miscellaneous expenses included water and electric power charges etc.

Financing

Financing includes both debt and equity. To reduce the early-stage negative cash flow do to the initial investment, it was assumed there was a bank loan of ₩1,500,000 thousand (Korean won) at a nominal (i.e., including inflation) fixed interest rate of 6% and a 10-year redemption period. The model allows this interest rate to be set directly or as a function of the inflation rate, if desired. The bank's loan initiation

fee was paid only at the start of the loan, which represented 47% of total initial investment.

Loans are commonly repaid in Korea using constant principal repayments, which means that the interest payments and total loan payments vary each year. This was the method incorporated into the model. However, to allow flexibility in financing and repayment options, the spreadsheet model is constructed so that the loan may also be repaid using constant loan repayments, which means that the interest payments and loan principal repayments vary with each loan payment, but that each total annual loan payment is identical. In both cases, while interest expenses are deducted from revenue for tax purposes, principal repayments are not deducted.

The before finance and tax weighted average cost of capital is the minimum acceptable return rate on equity investment in the plant, which was set at 10.0%. This is a pre-tax nominal rate; that is, it includes inflation. It is the before finance and tax discount rate that was used in the discounted cash flow analysis. The before tax weighted average cost of capital (8.0%) was calculated by weighting the equity discount rate (10.0%) by the portion of equity in the initial financing and the bank's loan interest rate (6.0%) by the portion of debt in the initial financing. The after tax weighted average cost of capital (7.3%) was calculated by adding the cost of equity to the after tax cost of debt with both costs weighted according to the initial equity-debt mix.

Tax

National and local income taxes were incorporated at the rates of 10% and 1% respectively when income was ₩0 to ₩0.2 billion, and 20% and 2% when income was between ₩0.2 billion and ₩2 billion.

Revenue analysis

The primary market for heat and electricity produced from the power plant was assumed to be the rural town in which it was built. Table 2 shows annual revenues from heat and power production and details are as follows.

Revenues from selling electricity power

Before calculating electricity sales revenue per year, a calculation was needed for the unit selling price of power, which comprises the system marginal price (SMP) of electricity and the market price of a REC. The (SMP) is an official power price of the Korea Power Exchange. To promote the use of renewable energy, the government enacted RPS in 2014, under which a plant producing power from renewable sources such as biomass and water can issue the REC that can be traded in the market. When a forest biomass REC is sold to Korea Electric Power Corporation (KEPCO), the REC is provided with a 1.5 weight factor (i.e. $\times 1.5$) above the SMP to determine its market price (Korea Ministry of Trade,

Industry and Energy 2014). This REC weighting factor helps to make the production of biomass-generated energy financially feasible.

Revenues from selling heat

The combined heat and power generator of this study produced 1436 Mcal of heat energy as well as 500kW of electricity per hour. Unlike electricity, selling heat requires facilities to be built for sending heat to households, which usually involves high costs. The unit selling price of heat for household was collected from Korea District Heating Corporation and used in the cost analysis, although to realize these heat sales revenues, additional distribution infrastructural investment may be required.

Other assumptions used for the economic analysis

The other assumptions are as follows:

- Inflation was 3% and fixed over a 20-year project period.
- A working capital fund required for running the plant was set at 2% of total annual revenue and recovered at the end of year 20.
- Capital costs including wood grab loader, chipper, dryer, gasifier, generator, construction, and land begin at year 0 and other costs including forest biomass, labor and office management, interest, and reserved fund begin at year 1.
- Straight-line depreciation is used for all depreciable assets.
- No capital gains taxes were assumed. Also, no tax allowances were made for capital loss carry backs or carry forwards.
- No capital equipment would be replaced in year 20.
- Total costs and revenue occurred at the end of each year over a 20-year period.
- Assets with residual values at the end of year 20 are valued at book for financial feasibility calculations.

Development of a cash flow model

The cash-flow model includes a number of parameters that are related to basic economic assumptions and investment financing options. The basic economic assumptions include the economic life of the project, and inflation rates for costs and revenue over the project period. It should be noted that inflation does not change the bank interest rate charged on the loan, unless that rate has been set as a function of inflation. Similarly, the inflation rate does not change the depreciation expenses as they become fixed when assets are purchased.

To illustrate the model, the cash flow calculations extended out for 20 years (Figure 2). The cash flow model is divided into four major sections, which allow an analyst to focus on specific cash flows to determine the impacts of changes in various variables or options:

- I. Capital cash flows: include land, buildings, and equipment that are replaced as necessary. Capital cash flows also include investments in working capital. Note in this section that equipment is replaced at the end of its economic life and that estimated salvage values are increased by the inflation rate. If equipment economic lives are changed, the

Table 2. Summary of annual revenues from selling heat and electricity.

Revenue parameter	Unit production	Production to selling ratio (%)	Unit selling price (Korean won)	Annual revenue (1000 won/year)
Power	500 kW/hour	90	281.0*	1,416,761
Heat	1436 Mcal/hour	60	67.6**	535,767

Notes: *Average SMP + average price of REC $\times$ weight (1.5).

**Unit selling price of heat for household in 2016 (Korea District Heating Corporation 2017).

		Part II: Capital Cash Flows																				
Capital Investment		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Wood grist loader	(54,000)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chipper	(258,000)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dryer	(100,000)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gravifier	(500,000)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Generator	(500,000)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Building	(20,000)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Land	(500,000)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Working capital	(28,350)	(28,350)	(28,350)	(28,077)	(28,077)	(28,077)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)
Capital investment	(2,932,350)	(28,350)	(28,350)	(28,077)	(28,077)	(28,077)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)
Capital Asset Salvage and Recovery																						
Wood grist loader salvage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chipper salvage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dryer salvage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gravifier salvage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Generator salvage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Building salvage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Land sale	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Working capital recovery	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subtotal: Capital recovery	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subtotal: Net capital cash flow	(2,960,700)	(28,350)	(28,350)	(28,077)	(28,077)	(28,077)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)
Part III: Operating Cash Flows																						
Revenue from sale of electricity and heat		-	970,751	999,873	1,009,870	1,000,766	1,002,589	1,102,366	1,109,127	1,109,801	1,209,718	1,266,810	1,304,608	1,349,746	1,384,059	1,425,590	1,468,348	1,512,368	1,557,770	1,604,503	1,652,688	1,702,217
Revenue from heat		-	448,759	460,162	473,946	488,185	502,831	517,545	533,453	549,457	565,541	581,819	600,408	618,419	636,971	656,080	675,743	696,026	716,917	738,424	760,577	783,384
Subtotal: Revenue from electricity and heat		-	1,419,510	1,460,035	1,503,816	1,548,951	1,595,420	1,640,282	1,692,281	1,749,258	1,795,659	1,898,229	1,905,016	1,968,165	2,021,030	2,081,670	2,144,110	2,208,394	2,274,687	2,342,927	2,413,115	2,485,611
Operating Expenses		-	(487,227)	(500,289)	(511,208)	(520,320)	(546,890)	(561,041)	(579,884)	(597,380)	(615,200)	(633,366)	(652,777)	(672,360)	(692,131)	(712,107)	(734,206)	(756,321)	(778,450)	(802,832)	(828,148)	(851,728)
Forest biomass procurement		-	(314,210)	(329,851)	(345,341)	(363,271)	(382,000)	(401,395)	(421,700)	(443,500)	(466,000)	(488,900)	(512,411)	(541,924)	(570,931)	(599,828)	(631,277)	(664,384)	(699,402)	(734,360)	(775,401)	(816,739)
Labour & office management		-	(2,866)	(3,100)	(3,352)	(3,625)	(3,921)	(4,240)	(4,586)	(4,960)	(5,364)	(5,801)	(6,274)	(6,785)	(7,338)	(7,946)	(8,619)	(9,369)	(10,099)	(10,877)	(11,742)	(12,699)
Maintenance & repair		-	(13,954)	(15,039)	(16,244)	(17,614)	(19,059)	(20,602)	(22,241)	(24,097)	(26,081)	(28,195)	(30,440)	(32,824)	(35,350)	(38,020)	(40,836)	(43,799)	(46,919)	(50,195)	(53,727)	(57,519)
Wood grist loader		-	(1,950)	(2,170)	(2,406)	(2,658)	(2,936)	(3,240)	(3,571)	(3,929)	(4,315)	(4,729)	(5,172)	(5,644)	(6,146)	(6,678)	(7,240)	(7,832)	(8,454)	(9,106)	(9,788)	(10,499)
Chipper		-	(14,228)	(14,976)	(15,745)	(16,538)	(17,356)	(18,197)	(19,061)	(19,948)	(20,859)	(21,794)	(22,753)	(23,736)	(24,743)	(25,774)	(26,828)	(27,905)	(28,996)	(30,100)	(31,216)	(32,344)
Dryer		-	(21,630)	(23,330)	(25,298)	(27,461)	(29,801)	(32,303)	(34,961)	(37,780)	(40,764)	(43,918)	(47,246)	(50,754)	(54,448)	(58,334)	(62,418)	(66,698)	(71,172)	(75,938)	(80,998)	(86,352)
Gravifier		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Generator		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Building		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subtotal: maintenance & repair		-	(55,724)	(60,260)	(65,177)	(70,489)	(76,234)	(82,470)	(89,187)	(96,400)	(104,084)	(112,246)	(120,877)	(129,980)	(139,551)	(149,588)	(159,191)	(169,359)	(179,092)	(189,400)	(199,282)	(209,739)
Fuel cost		-	(8,518)	(8,715)	(8,916)	(9,120)	(9,327)	(9,537)	(9,750)	(9,966)	(10,185)	(10,406)	(10,629)	(10,854)	(11,081)	(11,310)	(11,540)	(11,772)	(12,006)	(12,241)	(12,478)	(12,717)
Wood grist loader		-	(13,038)	(13,439)	(13,842)	(14,247)	(14,654)	(15,062)	(15,472)	(15,884)	(16,298)	(16,714)	(17,132)	(17,551)	(17,972)	(18,395)	(18,819)	(19,244)	(19,670)	(20,097)	(20,525)	(20,954)
Chipper		-	(13,857)	(14,260)	(14,664)	(15,070)	(15,478)	(15,887)	(16,297)	(16,708)	(17,120)	(17,533)	(17,947)	(18,362)	(18,778)	(19,194)	(19,611)	(20,028)	(20,446)	(20,864)	(21,282)	(21,699)
Subtotal: Fuel cost		-	(35,413)	(36,414)	(37,416)	(38,418)	(39,420)	(40,422)	(41,424)	(42,426)	(43,428)	(44,430)	(45,432)	(46,434)	(47,436)	(48,438)	(49,440)	(50,442)	(51,444)	(52,446)	(53,448)	(54,450)
Subtotal: Operating expenses		-	(91,141)	(96,675)	(102,593)	(108,899)	(115,601)	(122,803)	(130,005)	(137,207)	(144,409)	(151,611)	(158,813)	(166,015)	(173,217)	(180,419)	(187,621)	(194,823)	(202,025)	(209,227)	(216,429)	(223,631)
Subtotal: Net operating cash flow		-	548,369	593,360	581,223	560,052	579,819	617,479	659,071	682,058	744,419	753,819	764,199	789,785	821,819	859,060	896,419	933,971	971,721	1,009,571	1,047,421	1,085,271
Subtotal: Net cash flow before finance and tax		(2,960,700)	(28,350)	(28,350)	(28,077)	(28,077)	(28,077)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)	(28,350)

Figure 2. Cash flow tableau for operating a small-sized combined heat and power plant.



alterations will be reflected in an automatically-updated cash flow table.

- II. Operating cash flows: are the day-to-day revenues and expenses that must be recovered in order for the business to operate over the short term.
- III. Financing cash flows: consist of cash flows related to any debt that is taken on to help pay for the capital assets. They are divided into the initial loan, which is a positive cash flow, tax-deductible interest expenses, and loan principal repayments.
- IV. Taxes: based on taxable income.

In the cash flow table, three rows are highlighted in yellow that represent the most important net cash flows:

- before finance and tax;
- before tax; and
- after tax.

To aid in feasibility analysis, *pro forma* income statements are also calculated and are shown (Figure 3). In the *pro forma* income statements, only revenues and expenses are shown. Earnings before interest, taxes, depreciation, and amortization (EBITDA) is shown, along with earnings before interest and taxes (EBIT), earnings before taxes, and finally net income (loss).

All financial measures are computed three ways: before finance and tax; before tax; and after tax. NPVs and the payback period are both computed using the three highlighted nominal cash flows and the three costs of capital (10.0%, 8.0%, and 7.3%, respectively). The payback period is the year in which the accumulated cash flow, including a capital charge based on the respective cost of capital, turns positive. If the accumulated cash flow does not turn positive over the 20-year planning period, then an “Infeasible” message is returned, indicating that the capital and the minimum required return on capital are never completely paid back. IRRs are computed both on the basis of nominal cash flows that include inflation, and on a real won basis, which are over and above inflation.

Sensitivity analysis

Of greater concern was the sensitivity of the financial feasibility of running the plant to changes in important factors determining costs and revenues. Several types of sensitivity analyses were built into the model through the adjustment of sensitivity factors to make it easy for users to get a sense of the importance of various cost and revenue assumptions. These are percentages that are multiplied by the costs or revenues so that an analyst can see the impact of percentage changes in these variables on the overall financial return measures. This method was used to test for changes in forest biomass prices and revenue from sales of heat. This method was also used to examine the sensitivity of financial returns to changes in REC prices, which easily fluctuate according to supply and demand and constitute a major portion of the electricity selling price.

Result and discussion

Financial feasibility of running a small-sized combined heat and power plant

Table 3, taken from the model's results, shows the financial feasibility of a small-sized combined heat and power plant.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Revenue from heat and power	-	1,417,510	1,400,035	1,303,896	1,548,851	1,595,420	1,442,282	1,692,281	1,742,358	1,795,659	1,849,529	1,905,014	1,962,165	2,021,030	2,081,661	2,144,110	2,208,434	2,274,687	2,342,927	2,413,215	2,485,612
Operating expenses	-	(485,227)	(500,299)	(511,328)	(520,797)	(528,690)	(535,031)	(539,894)	(543,280)	(545,280)	(546,008)	(545,577)	(544,000)	(541,324)	(537,551)	(532,680)	(526,720)	(519,680)	(511,560)	(502,360)	(492,080)
Forest biomass procurement	-	(141,210)	(142,851)	(144,541)	(146,270)	(148,038)	(149,846)	(151,694)	(153,582)	(155,510)	(157,478)	(159,486)	(161,534)	(163,622)	(165,750)	(167,918)	(170,126)	(172,374)	(174,662)	(176,990)	(179,358)
Labour & office management	-	(10,570)	(10,670)	(10,770)	(10,870)	(10,970)	(11,070)	(11,170)	(11,270)	(11,370)	(11,470)	(11,570)	(11,670)	(11,770)	(11,870)	(11,970)	(12,070)	(12,170)	(12,270)	(12,370)	(12,470)
Manufacturing Exp. cost	-	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)	(13,570)
Subtotal: Operating expenses	-	(875,218)	(901,560)	(927,718)	(953,837)	(979,948)	(1,006,060)	(1,032,172)	(1,058,284)	(1,084,396)	(1,110,508)	(1,136,620)	(1,162,732)	(1,188,844)	(1,214,956)	(1,241,068)	(1,267,180)	(1,293,292)	(1,319,404)	(1,345,516)	(1,371,628)
Subtotal: EBITDA	-	542,292	498,736	382,568	1,028,054	1,066,730	907,251	1,152,387	1,199,078	1,250,379	1,301,679	1,352,979	1,404,279	1,455,579	1,506,879	1,558,179	1,609,479	1,660,779	1,712,079	1,763,379	1,814,679
Depreciation expenses	-	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)	(189,236)
Subtotal: EBIT	-	353,056	309,500	193,332	838,818	877,494	718,015	963,151	1,009,842	1,061,143	1,112,443	1,163,743	1,215,043	1,266,343	1,317,643	1,368,943	1,420,243	1,471,543	1,522,843	1,574,143	1,625,443
Loan cost and interest expense	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)
Subtotal: Earnings before taxes (EBT)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)	(7,500)
Taxes	-	(57,872)	(61,433)	(65,000)	(68,567)	(72,133)	(75,700)	(79,267)	(82,833)	(86,400)	(90,000)	(93,600)	(97,200)	(100,800)	(104,400)	(108,000)	(111,600)	(115,200)	(118,800)	(122,400)	(126,000)
Net income (loss)	(7,500)	(65,372)	(72,933)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)	(72,500)

Figure 3. Pro forma income statements for operating a small-sized combined heat and power plant.

Table 3. Summary of financial indicators over 20 years.

	NPV (₩million)	Nominal IRR (%)	Real IRR (%)	PP (year)
Before finance and tax	1229	15.5	12.1	11
Before tax	2055	20.1	16.6	8
After tax	1526	15.7	12.3	8

The project's IRR was 12.3% after accounting for inflation and income taxes, given the assumptions used.

Revenue that would be earned from selling electricity and heat over the 20-year planning period discounted at the 7.3% after tax cost of capital totaled ₩18,441 million. On an annualized basis it came to ₩1779 million. After-tax profits in addition to the after-tax cost of capital represented about 8.3% of the total discounted revenue. Forest biomass procurement was the largest single cost and represented 34.0% of the total revenue, followed by other operating costs (32.9%), and net capital costs (20.4%) (Figure 4).

It is noteworthy that, in this example, the loan financing was not a net cost, but rather resulted in a small net benefit (₩74 million). This was because the bank interest rate (6.0%) was less than the before finance and tax equity cost of capital (10.0%) and the project was earning a rate of return that was greater than the loan rate. The result was positive financial gearing that increased the equity rates of return, which were shown by the before tax and after tax IRRs that were higher than the before finance and tax IRRs.

Sensitivity analysis on key cost and revenue variables

The quickest way of measuring the importance of costs in a business enterprise is to divide them by sales revenue. The larger the percentage of costs in relation to total sales revenues, the more sensitive net profits (or losses) will be to changes in those costs. Our analysis showed that forest biomass procurement costs were the largest component of total capital costs and that capital costs, while significant at 20.4%, are less important than operating costs in determining the plant's profitability (Figure 4).

Sensitivity analysis by forest biomass price change

As the forest biomass price per unit increased from 60% to 150% of its base value, NPV before finance and tax

discounted at 10.0% decreased from ₩3.3 billion to -₩1.3 billion and real IRR from 20.0% to 0.3%. Payback period increased from 4 years at 60% to 20 years at 120% but it was infeasible after 130% (Figure 5). If the forest biomass price per unit increases to over 130%, it means that renewably-generated electricity would not receive any marketplace premium over any other electricity. In this case, NPVs or IRRs turn negative and the payback period becomes infeasible – that is, the project's capital costs are never paid back.

NPV before tax discounted at 8.0% decreased from ₩4.4 billion to -₩0.9 billion and real IRR from 30.4% to -0.5%, while payback period increased from 2 years at 60% to 20 years at 130% and was infeasible after 140%. NPV after tax discounted at 7.3% decreased from ₩3.5 billion to -₩0.9 billion and real IRR from 23.0% to -0.7%, while the payback period increased from 6 years at 60% to 20 years at 130% and was infeasible after 140%.

Sensitivity analysis by change of REC price

As the revenue from power selling per unit changed from 60% to 150% of its base value, NPV before finance and tax discounted at 10.0% increased from -₩1.6 billion to ₩4.9 billion and real IRR from -2.0% to 25.7%, while payback period decreased from 17 years at 90% to 5 years at 150% and was infeasible before 80% (Figure 6). NPV before tax discounted at 8.0% increased from -₩1.4 billion to ₩6.3 billion and real IRR from -3.3% to 41.0%, while payback period decreased from 20 years at 80% to 3 years at 150% and was infeasible before 70%. NPV after tax discounted at 7.3% increased from -₩1.4 billion to ₩5.1 billion and real IRR from -3.3% to 31.3%, while payback period decreased from 20 years at 80% to 3 years at 150% and was infeasible before 70%.

Sensitivity analysis by revenue change from selling heat

Unlike power, selling heat is relatively limited and uncertain because it requires additional and expensive distribution infrastructure (i.e., pipes) to send heat to consumers. However, heat sales are critical to the facility's overall economics. The revenue from selling heat was assumed to change from 60% to 150% of its base value for the analysis. The result was that NPV before finance and tax discounted at 10.0% increased from -₩0.6 billion to ₩3.5 billion and real IRR

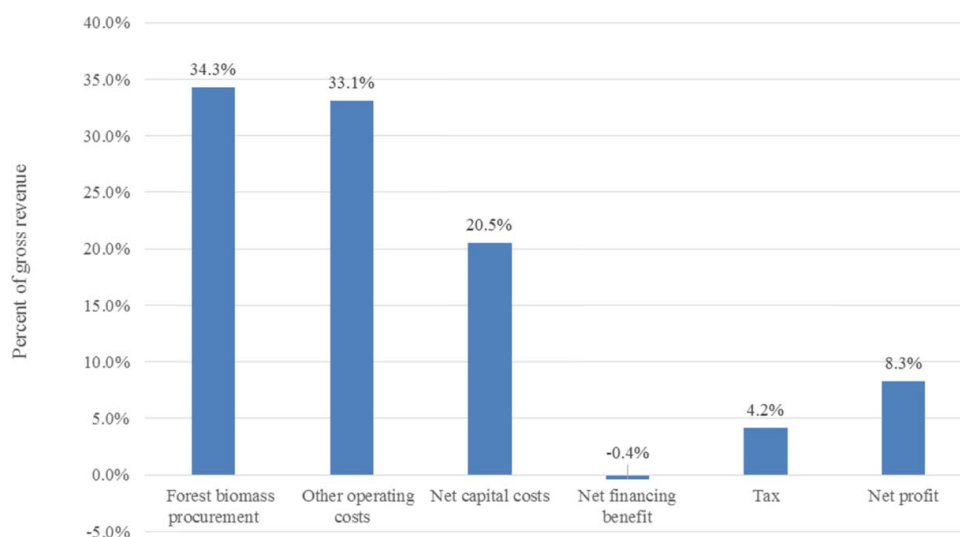


Figure 4. A small-sized and combined heat and power plant discounted after-tax costs and NPV as a portion of discounted revenue.

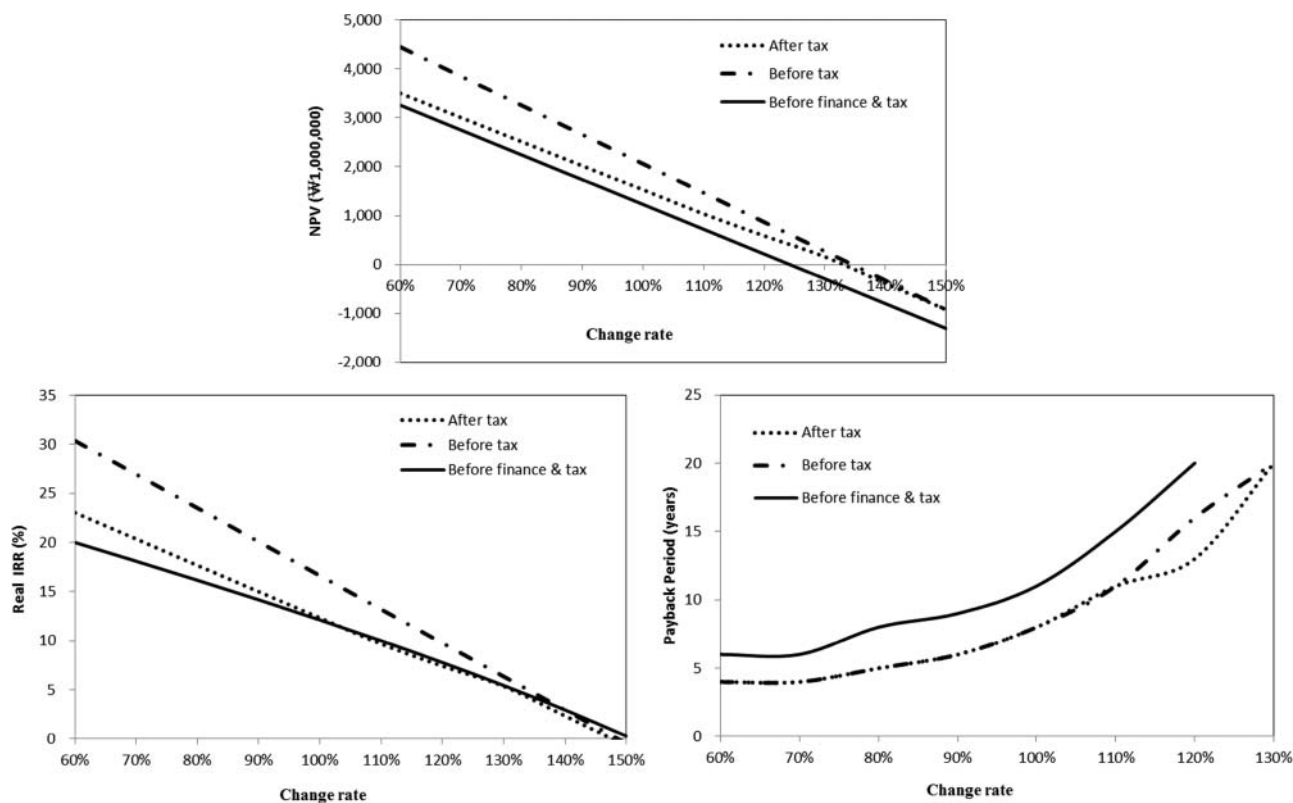


Figure 5. Impact of changes in forest biomass procurement price on NPV, Real IRR, and PP.

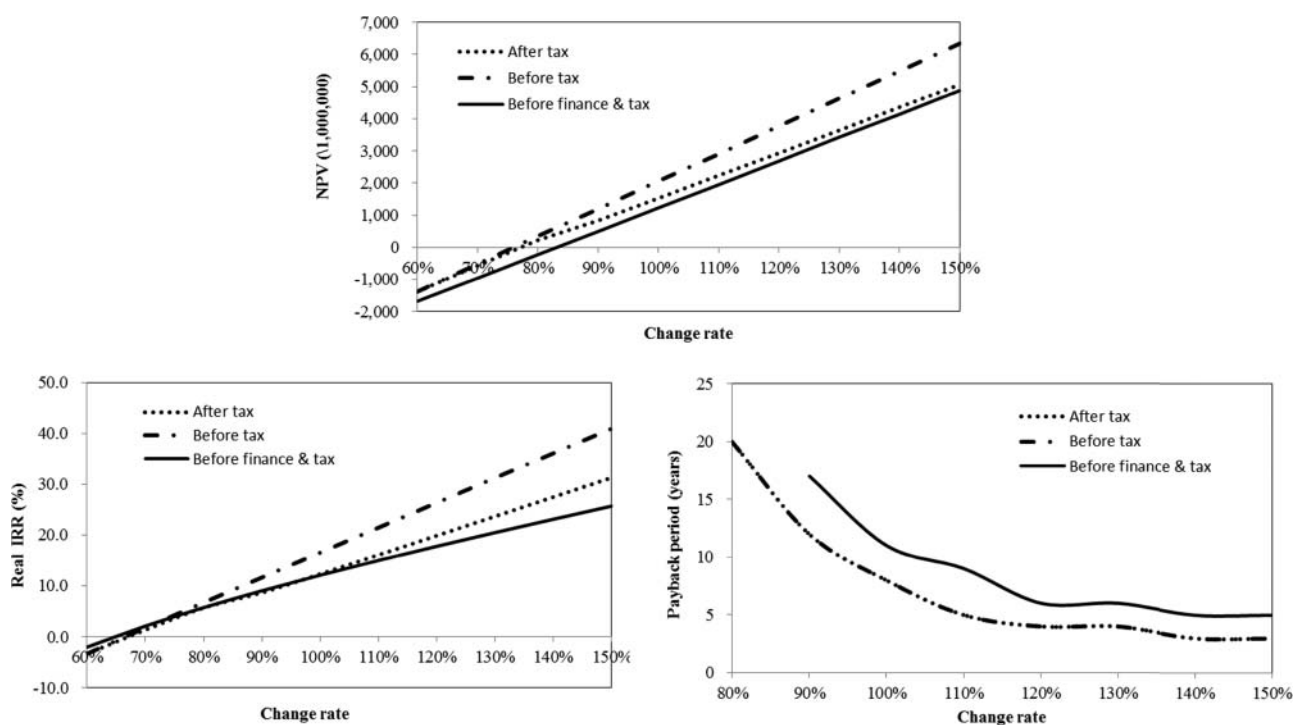


Figure 6. Impact of changes of REC price on NPV, IRR, and PP.

from -2.0% to 25.7%, while the payback period decreased from 20 years at 80% to 6 years at 150% (Table 4). NPV before tax discounted at 8.0% increased from -₩0.1 billion to ₩3.7 billion and real IRR from 4.1% to 32.1%, while the payback period decreased from 20 years at 70% to 4 years at 150%. NPV after tax discounted at 7.3% increased from

-₩0.2 billion to ₩3.8 billion and real IRR from 3.4% to 24.3%, while the payback period decreased from 19 years at 70% to 4 years at 150%. Note that at revenue recovery rates on heat of 60% or less of our base case, the payback period becomes infeasible; that is, the capital investment is never recovered (Table 4).

Table 4. Impact of changes in revenue from heat on NPV, IRR and PP.

Change ratio (%)	Real IRR (%)			NPV (1,000,000)			Payback period (years)		
	After tax	Before tax	Before finance and tax	After tax	Before tax	Before finance and tax	After tax	Before tax	Before finance and tax
60%	3.4	4.1	3.8	-189	-117	-615	inf	inf	inf
70%	6.0	7.3	6.1	287	426	-154	19	20	inf
80%	7.8	10.4	8.2	662	969	307	13	13	20
90%	9.9	13.5	10.2	1079	1513	768	11	11	13
100%	12.3	16.6	12.1	1526	2056	1229	8	8	11
110%	14.7	19.7	14.0	1974	2599	1690	6	6	9
120%	17.1	22.8	15.8	2421	3143	2151	5	5	8
130%	19.5	25.9	17.5	2869	3686	2613	4	5	7
140%	21.9	29.0	19.2	3316	4229	3074	4	4	6
150%	24.3	32.1	20.9	3764	4773	3535	4	4	6

Note: inf = infeasible.

Conclusion

Economic analysis was conducted for a small-sized (500kW/hour) combined heat and power plant with a 20-year life that would provide a rural town surrounded by forested mountains with heat and power using forest biomass. Cost factors that were considered in the analysis included wood procurement, a wood grab loader, a chipper, a chip dryer, a gasifier, a generator, land and building, wages, and office management. All the cost factors were calculated based on the 2016 market values for logs, machine manufacturers' prices, and a literature review. Revenues were estimated from selling heat and electricity using the 2016 average prices that were sourced from Korea District Heating Corporation and Korea Power Exchange, respectively. Using a spreadsheet program, cash flows for costs and revenues were arranged to calculate net present value, internal rate of return and payback period of the plant. Calculations were done three ways: before finance and tax; before tax; and after tax. Also, sensitivity analyses were performed on the cost of wood procurement, and revenues from selling heat and electricity, which were the most significant factors affecting the economic feasibility.

The results showed that the project was not so promising and internal rate of return was about 12.3% after tax. As a percentage of the total revenue over the 20-years project, wood purchasing cost was the largest item representing 34.3% of the revenue, followed by other operating costs (33.1%), net capital costs (20.5%), and net profit (8.3%).

Sensitivity analysis by forest biomass price showed that NPV after tax discounted at 7.3% decreased from ₩3.5 billion to -₩0.9 billion and real IRR from 23.0% to -0.7% as the forest biomass price per unit was changed from 60% to 150% of its base value. While the payback period increased from 6 years at 60% to 20 years at 130% and was infeasible after 140%. As the REC price increased from 60% to 150% of its base value, NPV after tax discounted at 7.3% increased from -₩1.4 billion to ₩5.1 billion and real IRR from -3.3% to 31.3%, while payback period decreased from 20 years at 80% to 3 years at 150% but was infeasible before 70%. When the revenue from heat selling was assumed to increase from 60% to 150% of its base value, NPV after tax discounted at 7.3% increased from -₩0.2 billion to ₩3.8 billion and real IRR from 3.4% to 24.3%, while payback period decreased from 19 years at 70% to 4 years at 150%.

For such an investment to succeed, a sustained and affordable supply of forest biomass from around mountain villages is the most important prerequisite for operating the plant,

and development of an optimized timber harvest system is needed through evaluation of the usable forest resource and annual timber harvest planning (Han et al. 2011). Also note that the plant's economic viability depends on the amount of heat sales. Ideally a plant would be located where the piping already exists to distribute a plant's excess heat, because costs can be high to install such infrastructure. Finally, a biomass gasification plant's financial feasibility will depend on premiums paid for renewably-generated electricity, especially if extra margin weightings exist for biomass-generated electricity, because without the continuance of these premiums, a small-sized combined heat and power biomass gasification plant in the Republic of Korea would likely not be economic.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education [grant number NRF- 2017R1A6A3A11034434].

References

- Brinker RW, Miller D, Stokes BJ, Lanford BL. 1989. Machine rates for selected forest harvesting machines. Circular 296. Alabama Agricultural Experiment Station. Auburn (AL): Auburn University.
- Choi DH, Lee SY, Son YM, Park GS. 2005. Economic validity and introduction strategy of woody bio-energy in Korea. *J Solar Energy*. 4(1):37–46.
- Han HS, (Ted) Bilek EM, Dramm J, Loeffler D, Calkin D. 2011. Financial feasibility of a log sort yard handling small-diameter logs: a preliminary study. *West J Appl For*. 26(4):174–182.
- Ince PJ, (Ted) Bilek EM, Dietenberger MA. 2011. Modeling integrated biomass gasification business concepts. USDA Research Paper.
- Korea District Heating Corporation. 2017. Information on heating supply. Available from <https://www.kdhc.co.kr/content.do?sgrp=S11&siteCmsCd=CM3651&topCmsCd=CM3800&cmsCd=CM3856>.
- Korea Energy Agency. 2012. A handbook of energy and climate change. Yongin: Korea Energy Agency.
- Korea Energy Agency. 2016. Korea new & renewable energy supply statistics of 2015. Yongin: Korea Energy Agency.
- Korea Forestry Promotion Institute. 2016. Quarterly market prices of domestic timber. Seoul: Korea Forestry Promotion Institute.
- Korea Forest Research Institute. 2014. Forest biomass resource and map of Korea. Seoul: Korea Forest Research Institute.
- Korea Ministry of Trade, Industry & Energy. 2014. Management and operating instructions on renewable energy portfolio standard. Seoul: Korea Ministry of Trade, Industry & Energy.

- Korea Power Exchange. 2017. Report on REC trade status of 2016. Available from <http://rec.kpx.info/main.jsp?menuId=502>.
- Korea Presidential Committee on Green Growth. 2009. National strategy for green growth and five year plan. Seoul: Korea Presidential Committee on Green Growth.
- Lee JY. 2009. A study on the energy utilization of forest biomass. Policy Studies 2009-35. Suwon: Gyeonggi-do Research Institute.
- Seo GY. 2013. Case analysis on combined heat and power generation using woody biomass and economic comparison with gasification [MS Thesis]. Seoul: Green School, Korea University.