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Introduction of renewable energy sources in the district heating system of Greece

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ABSTRACT

The DH system of Greece, mainly supported from lignite fired stations, is facing lately significant challenges. Stricter emission limits, decreased efficiency due to old age and increased costs are major challenges of the lignite sector and are expected to result in the decommissioning of several lignite-fired units in the coming years. As a result, managers of DH networks are currently investigating alternative scenarios for the substitution of thermal power that it is expected to be lost, through the integration of RES into the system. In this paper, the DH systems of Kozani and Ptolemaida are examined regarding possible introduction of RES. The first study examines district heating of Kozani and alternative future options for covering a part of city's thermal load whereas the second study refers to a biomass CHP plant (ORC technology, 1 MWe, 5 MWth) to be powered from a biomass mixture (wood chips and straw).

Keywords:

CHP, biomass boiler, wood pellets, straw, economic analysis, feed in tariff, sensitivity analysis

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1. Introduction

DH systems provide heating for a wide range of customers, from residential building to agricultural sector, including commercial, public and industrial customers. District energy systems have flexibility in using a wide variety of energy sources as feedstock. The energy source for district heating systems is usually a steam boiler, typically fired by natural gas, although other sources are possible. Hybrid systems, using a combination of natural gas, wood-waste, municipal solid waste and waste heat from industrial sources are possible, and often more economical [1].

Using forest biomass, namely residues from logging activities, primary and secondary mill residues, urban wood wastes, and energy crops, in district energy systems provides the opportunity to produce heat and/or power with limited environmental impacts by utilizing renewable source of energy and increasing conversion efficiency simultaneously. District energy systems have higher efficiencies than individual energy systems as they minimize energy wastes [2].

Gustavsson and Karlsson, in an investigation to choose the best energy system to heat detached homes in Sweden, showed that district heating was a more efficient and less expensive system with less environmental impacts than decentralized and electric heating systems [3]. Generally, differences in primary energy use, emission and cost between the energy systems analysed depend less on the fuel used in the system than on the type of system chosen. Refined wood fuels lead to very high production costs and therefore are not cost-competitive with other energy sources. However, although the cost of the pellet boiler systems is higher than the cost of fossil-fuel-based local heating systems, the district heating systems and the heat pump systems, they may still be a cost-efficient alternative with low impact on global warming for houses where the use of district heating

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or the availability of heat sources for heat pumps is constrained [3].

In Europe, the share of renewable energy used in DH is constantly increasing, while the use of coal, oil and their derivatives decreases. Due to the need for rationalized energy consumptions, biomass use in industrial power plants and district heating & cooling is expected to roughly double, reaching 105 Mtoe in 2020, which represents about half of the gross inland consumption [4]. Projections for 2050 are even higher, as high temperature industrial process heat will highly rely on biomass and industries will need to produce energy in a more environmental friendly way. The above, combined with the use of cogeneration technologies make the DH as one of the most popular sources for heating. Furthermore, the obligation of reducing CO_2 emissions and increasing the share of renewable energy to meet European requirements is considered as one of the main driving forces for the development of the DH sector.

Several studies can be found in the literature, concerning feasibility and efficiency of DH systems based on biomass and natural gas. Lazzarin and Noro [6] analyzed the major DH natural gas based technologies (steam and gas turbines, internal combustion engine, combined cycles). They compared the cost of heat and power produced in these plants to the cost of producing the same quantity of electrical energy by a reference Gas Turbine Combined Cycle (GTCC) and the cost of heat production by modern local heating technologies using natural gas as fuel (condensing boilers, gas engine and absorption heat pumps).The conclusion of this study was that district heating cannot always be considered as the most efficient system available for producing heat and power. When using natural gas as fuel, CHP systems are really the best only when the most efficient technologies (GTCC) are employed.

In a study of Difs et al. the economic effects and the potential for reduced CO_2 emissions when biomass gasification applications are introduced in a Swedish district heating system are evaluated. The study shows that introducing biomass gasification in the DH system will lead to economic benefits for the DH supplier as well as reduce global CO_2 emissions. Biomass gasification significantly increases the potential for production of high value products (electricity or synthetic natural gas, SNG) in the DH system. However, which form of investment is most profitable depends highly on the level of policy instruments for biofuels and renewable electricity. Biomass gasification applications can thus be interesting for DH suppliers in the future, and may be a vital measure to reach the 2020 targets for greenhouse gases and renewable energy, given the continued technology development and long-term policy instruments [6].

Fahlen and Ahlgren [7] study refers to the options for different levels of integration of biomass gasification with an existing NGCC CHP plant, both for CHP production and for production of biofuels. The economic robustness of different solutions is investigated by using different sets of parameters for electricity price, fuel prices and policy tools. In this study, it is assumed that not only tradable green certificates for electricity but also tradable green certificates for transport fuels exist. The economic results show strong dependence on the technical solutions and scenario assumptions but in most cases a stand-alone SNG-polygeneration plant with district-heat delivery is the cost-optimal solution. Its profitability is strongly dependent on policy tools and the price relation between biomass and fossil fuels.

Marbe et al. [8] compare biomass based CHP based on conventional steam turbine technology with biomass integrated gasification combined cycle (BIGCC) CHP. The results show the clear economic advantage of this type of co-operation. Under the assumed conditions for the study, an optimally sized conventional steam turbine CHP unit achieves the lowest cost of electricity. However, gasification-based CHP technologies generate significantly more electricity than conventional steam cycle technology, which results in higher net CHP plant revenue for a pressurised gasification CHP plant.

In the study of Borjesson and Ahlgren [9], the cost-effectiveness of different applications of biomass gasification is analysed. The study investigates whether, and under what conditions, combined heat and power (CHP) generation in biomass integrated gasification combined cycle (BIGCC) plants, as well as production of biofuels for transport in biomass gasification biorefineries, could be competitive alternatives to conventional technology options in district heating (DH) systems. Results from the study indicate that biomass gasification can be cost-competitive in DH systems, but that electricity prices and subsidy levels have large influence.

Stoppato [10] presented the results of the energetic and economic analysis of an ORC plant with nominal electric power of 1.25 MW which also produces 5.3 MW of heat. This plant is connected to the electric grid and to the local DH grid. The emissions have been evaluated and compared with those of the pre-existing situation: domestic boilers fed by natural gas or diesel oil. The analysis has shown that the present incentives lead to a not rational use of energy, since it is convenient to maximize electric production, with a total efficiency of about 15%, instead of cogenerating heat and electricity, with a total efficiency of about 80%. This is in agreement with the regulations, whose goal is only the production of electricity by renewable sources instead of fossil fuels.

Uris et al. [11] presented a techno-economic feasibility assessment of a biomass cogeneration plant based on an ORC. From the results obtained in this paper it is possible to conclude that subcritical recuperative ORC systems are technically and economically feasible in Spain when selling electricity to the grid at market prices (without subsidies) and thermal energy to the consumer below market prices.

In another study, of Erikssona et al. [12],a consequential life cycle assessment (LCA) was performed in order to compare district heating based on waste incineration with combustion of biomass or natural gas. The study comprises two options for energy recovery (combined heat and power (CHP) or heat only), two alternatives for external, marginal electricity generation (fossil lean or intense), and two options for the alternative waste management (landfill disposal or material recovery). The results indicate that combustion of biofuel in a CHP is environmentally favorable and robust with respect to the avoided type of electricity generation and waste management. A natural gas fired CHP is an alternative of interest if marginal electricity has a high fossil content. However, if the marginal electricity is mainly based on non-fossil sources, natural gas is in general worse than biofuels.

Truong and Gustavsson [13] found that with smaller district heat production systems the district heat production cost increases and the potential for cogeneration decreases. District heat production units are chosen based on the scale and variation of heat demand, the local availability and costs of energy sources, the investment cost of each technology, etc. District heating production systems (DHSs) with co/polygeneration of products other than heat, provide primary energy as well as environmental and cost benefits.

In small-scale DHSs, which are common in the existing Swedish DHSs, there are fewer technical options other than heat-only boilers due to the high specific investment cost under the small installed capacity of non-heat only boilers. Of the considered costs and conversion efficiencies of analysed district heat production units, cogeneration options are less attractive if the value of coproduced electricity from these plants is equivalent to that from stand-alone power plants. This observation is due to the high specific investment these technologies require compared to heat-only boilers at a small scale. A renewable-based district heat production system can be feasible as long as social-political contexts influence the use of non-fossil fuels. Moreover, along with change in fuel price, technological performance and investment costs, changes in heat load profile may influence the selection of technology for new district heat production units and the overall district heat production cost.

In this paper, two district heating networks of Greece based on fossil fuel (lignite) are examined regarding alternative options for covering a part of the nearby cities' thermal loads (Kozani and Ptolemaida). DH managers in Greece are particularly interested in heat and/or CHP production from renewable energy sources, which will allow the companies to continue to provide services to their customers with a minimum environmental impact. So, different technologies and alternative fuels are assessed in order to choose the most cost efficient solution for these networks. The investigation begins with the calculation of the technical parameters through the commercial thermodynamic simulation tool IPSEpro [14] and continues with the financial assessment via common economic indices. The novel feature which completes the analysis and pushes it one step further than the available literature is the consideration of a highly mutable politico-economic environment such as the Greek one, by examining the impact of new (dramatically lower) FIT values to come unexpectedly into force by a new Bill on the examined cases.

2. Methodology

In the next paragraphs the techno economic data for both DH systems are analysed and the basic assumptions are given according to the requests of DH managers. In the analysis of Ptolemaida DH system, the power plant simulator IPSEpro was used in order to yield the critical technical parameters, whereas in the examined scenarios of Kozani DH system typical technical parameters values were taken due to being in a much more preliminary stage. The commercial simulation tool IPSEpro enabled the optimization of the thermodynamic cycle of Ptolemaida's case.

2.1. Techno economic data for DH in Kozani

Three different scenarios for covering a total thermal demand of 70 MWth are analyzed:

- Scenario **K1: Natural Gas** - A natural gas boiler, producing useful thermal energy of 70 MWth.
- Scenario **K2: Biomass CHP** - Two CHP biomass boilers (of 70 MWth fuel thermal input each) with steam turbine unit, producing a total of 70 MWth and 35 MWe. Useful thermal efficiency is taken equal to 50%, while electric efficiency is taken equal to 25%, typical values for this kind of installations [15].
- Scenario **K3: Biomass boilers** -Two biomass boilers of 35MWth useful thermal output each, producing useful thermal energy of 70 MWth in total.

In both biomass scenarios K2 and K3, the boilers are fed by a fuel mixture of 70% wood pellets and 30% straw (on a thermal basis).This specified biomass mixture was an assumption dictated by DH company of Kozani due to expected favorable access to this kind of fuel. On the one hand, it is a common practice to combine 70–80% woody biomass with 30-20% herbaceous one, in order to lower the mixture price with the latter, but without posing extreme boiler requirements as e.g. in a 100% straw-fired boiler. On the other hand, pellets were chosen as the base woody biomass fuel (instead of e.g. chips) because the CHP plant of Kozani will entail large quantities of biomass, impossible to be covered by the local market, so the import of pellets seems more feasible.

Biomass and natural gas were the two most favourable fuels according to the requests of DH managers. Although lignite will keep on being the main fuel option in Greece in the near future, this study focused on environment-friendly alternatives with no lignite at all, such as biomass and to a lesser extent NG. Regarding Scenario K2 (Biomass CHP plant), the dimensioning and running are based on the heat demand, which after all is by default the main objective of both DH Companies under examination, that have a social character and are connected to the respective Municipal Authorities. In summer, when there is no heat demand, the CHP plant will run as only power producing plant, getting solely the revenues from the electricity production.

Two financing schemes are being examined. The first one consists of 20% own capital and 25% loan. The second one includes 30% own capital and 15% loan. In both of them, the subsidy is 55%. The construction time is assumed to be 2 years, while subsidy's payment is made in two installments: 50% during the first year of the construction phase, and rest 50% during the second year.

The project life is assumed to be 25 years, while the residual value of the investment is not included in the analysis, as there will be no liquidation at the end of the analysis period. Main financial parameters and fuels cost reduced to thermal energy are presented in Table 1. Natural gas price accounts for 13.12 €/GJ [16] while average prices for wood pellets and straw are 185 and 75 €/tn respectively (dictated by the DH company of Kozani, according to budgetary tenders from various biomass suppliers). Regarding loan duration and loan, tax and depreciation rates, typical values (dictated by the DH company of Kozani) are selected for the scenarios. Main income due to the operation of the new DH plant comes either from heat sale (K1: Natural Gas and K3: Biomass boilers) or from heat and electricity sale (K2: Biomass CHP). Selling prices are given also in Table 1.

The selected three scenarios are assessed concerning crucial economic indices such as Net Present Value (NPV), Internal Rate of Return (IRR) and payback period. A sensitivity analysis is also conducted regarding the selling price of thermal energy to citizens and the cost of biomass fuel. According to the DH Company, the main criterion for the investment to be sustainable is the expected IRR values to be above 12%.

2.2. Techno economic data for DH in Ptolemaidas

The scenario examined for Ptolemaida city is a Biomass Fired Boiler, for the Cogeneration of Heat near to 5 MWth and Power marginally lower than 1 MWel **(P: Biomass ORC CHP)**. The heat is supplied to the District Heating network of the city, with supply/return temperatures equal to 95/65 °C respectively and pressure equal to 25 bar. The magnitude of power output was chosen in order to achieve favorable Feed in Tariff

Table 1: Financial parameters and fuels cost for Kozani DH system.

Parameter	Value	Unit
Loan duration	15	years
Loan interest rate	6.5	%
Depreciation rate for equipment	10	%
Depreciation rate for infrastructures	5	%
Tax rate	26	%
Discount rate	5	%
Fuel	Cost	Unit
Natural gas	47.23	€/MWh-th
Biomass (70% wood pellets + 30% straw)	31.34	€/MWh-th
Sources of income (official values)	Cost	Unit
Electricity selling price-FIT	150	€/MWh-th
Heat selling price (current price of company)	43.50	€/MWh-th

(FIT) and easier licensing procedures. The most favorable technology for this order of magnitude small scale industrial application has proved to be the Organic Rankine Cycle (ORC) [17, 18, 19] A Clausius-Rankine Cycle is adopted, using an organic working fluid instead of water-steam, while thermal oil is used as heat carrier between the Boiler and the heat&power production circuit. The heat is supplied to the DH network during the 200 days of winter, while electricity is sold to the power grid operator during the whole year. The availability of the plant is considered to be equal to 90%. The fuel is a biomass mixture of 80% wood chips and 20% straw (on a thermal basis). Wood chips are chosen as the base woody biomass fuel, because unlike Kozani biomass cases, Ptolemaida CHP plant is a small scale plant, entailing much smaller biomass quantities than the Kozani one, therefore the local market has the capacity to cover the needs for wood chips.The properties of the 2 fuels are provided in Table 2.

The biomass CHP plant is financially evaluated by economic indices, i.e. NPV, IRR and payback period, taking into account the income from electricity and heat, the fuel cost and various operating&maintenance costs. The detailed parameters used in the techno-economic analysis are presented in Table 3.

It is to be noted that the table data were derived from official budgetary Technical and Financial quotations by several manufacturers, while the table assumptions for fuel costs and financing parameters were dictated by the DH Municipal Company of Ptolemaida after diligent market search.

3. Results

3.1. DH network of Kozani

3.1.1. Economic evaluation

Based on the techno economic data presented in paragraph 2.1, the economic evaluation of the three scenarios was conducted. In Table 4 total investment

Table 2: Fuels properties for P: Biomass ORC CHP.

			Wood chips	Straw
Proximate analysis	Ash	% w.t. (ar)	1.62	7.55
	moisture		40.00	8.45
	volatiles		49.20	5.55
	fixed C		9.18	8.45
Net calorific value	NCV	kJ/kg (ar)	10,63	6,03
Ultimate analysis	C		53.13	7.76
	H		5.96	5.75
	N		0.31	0.46
	O	w.t. (daf)	40.54	5.64
	S		0.04	0.12
	Cl		0.02	0.27

Table 3: Economic parameters for P: Biomass ORC CHP.

	Value	Unit
1. Fuel		
Wood chips price	80	€/tn
Straw price	60	€/tn
Mixture price reduced to NCV	24.37	€/MWh-th
2. Techno-economic		
Total investment cost	6.0	thousand €
Investment lifetime	20	years
Residual value	0	thousand €
Various annual operating costs:		
Personnel	160	thousand €
General O&M costs	1	% of CAPEX
Expendables	1	% of CAPEX
Insurance	0.5	% of CAPEX
Contigencies	2	% of other costs
3. Energy market (official values)		
Electricity selling price - FIT	230	€/MWh-el
Heat selling price (current price of company)	37.74	€/MWh-th
4. Financing		
Own capital	40	%
Subsidy	0	%
Loan	60	%
Loan duration	10	years
Loan interest	8	%
Type of loan dose	constant	constant/variable
Grace period	0	years
5. General financial information		
Inflation	2	%
Discount rate	8	%
Tax rate	30	%
VAT	not included	
Depreciation rate	10	%

Table 4: Investment, operating costs (plant's lifetime) and investments indices.

Scenario	Investment cost	Operating cost		NPV	IRR (%)	Payback period (years)
				Loan 25% (A scheme)		
			K1	–47.10 mil. €	–	>25
			K2	88.85 mil. €	16.15	9
K1						
Natural gas	16.14 mil. €	15.66 mil. €	**K3**	18.16 mil. €	18.18	8
K2				Loan 15% (B scheme)		
Biomass CHP	186.97 mil. €	39.10 mil. €				
K3						
Biomass boilers	26.60 mil. €	10.35 mil. €	**K1**	–46.59 mil. €	–	>25
			K2	92.59 mil. €	14.89	9
			K3	18.69 mil.€	16.79	8

and operating costs are presented and also results of financial analysis are given in terms of NPV, IRR and payback period for two loan shares (25% and 15%).

In scenario K1: Natural gas boiler, all financial indicators are negative, so this scenario cannot be considered sustainable. In scenarioK2: Biomass CHP, IRR and NPV values indicate a promising investment even though its high cost. Similarly, in scenario K3: Biomass boilers, all indices are positive and make a viable investment. So, according to DH Company of Kozani requirements, scenario K2: Biomass CHP and scenarioK3: Biomass boilers are considered profitable, presenting IRR values that exceed the desirable threshold of 12%.

3.1.2. Sensitivity analysis

A sensitivity analysis was also conducted in order to have a complete picture of these investments. The sensitivity analysis examines two critical variables: the selling price of thermal energy and the cost of biomass fuel, as they have direct impact on the investment characteristics.

a. Selling price of produced thermal energy

Initially the cost of thermal energy produced by a domestic oil boiler with an efficiency of 92% is calculated in order to have an idea of the current cost benefit for citizens using the district heating system. The specific production cost per unit of thermal energy, increased by 3% due to boiler maintenance costs, amounts to 143.81 € / MWh-th, taking into account that average oil price in Greece is about 1.28 €/lt (May 2014).

According to the pricing policy of the Company a discount rate of at least 25% compared to the equivalent costs of heat production from oil is mandatory. The selling price of thermal energy today is 43.50 € / MWh-th, so the discount rate in relation to the specific cost of domestic production from oil is 69.75%.The DH Company of Kozani wishes to maintain its pricing policy, which takes into consideration the social nature of the project. Through this policy, it became possible the penetration of district heating during the first years of its operation and the maintaining of its client base throughout the duration of its operation.

For discount rates from 69.75% to 25%, a full financial analysis for the three scenarios of the study was made keeping fuel cost unchanged.

For scenario K1 – Natural gas boiler, the sensitivity analysis indicated that the selling price of thermal energy should increase in order for the investment to be profitable. For financial scheme A, the selling price of thermal energy for which IRR takes the value of 12% is 58.06 €/MWh-th (see Figure 1). This means a price increase of 33.47% compared with the current price (43.50 €/MWh-th).Similarly, for financial scheme B, the selling price of thermal energy for which IRR takes the value of 12% is 58.13 €/MWh-th. This means a price increase of 33.63% compared with the current price (43.50 €/MWh-th).

For scenario K2 – Biomass CHP, it is noticed that the investment is profitable even for the current selling price of thermal energy (see Table 4). For both financial schemes, there is no need for price increase of thermal energy as long as IRR is above 12%.

For scenario K3 – Biomass boilers, it is noticed that the investment is profitable even for the current selling price of thermal energy, with higher IRR and a bit lower payback period compared to scenario K2 (see Figure 2 & Table 4).

b. Cost of biomass fuel

In this sensitivity analysis, the variation range of biomass and natural gas cost was set at ±20% of the baseline value (31.34 & 47.23 €/MWh-th respectively), keeping stable the selling price of thermal energy at 43.50 €/MWh-th. For scenarioK1 – Natural gas boiler, the results of the analysis showed that in case of an increase or decrease of natural gas price, the investment remains unprofitable with negative NPV values. For scenario K2 – Biomass CHP, the results of the analysis showed (Table 5) that in case of a potential increase in price of biomass up to 5% for financial schemes A and B the investment remains sustainable with IRR above 12%.

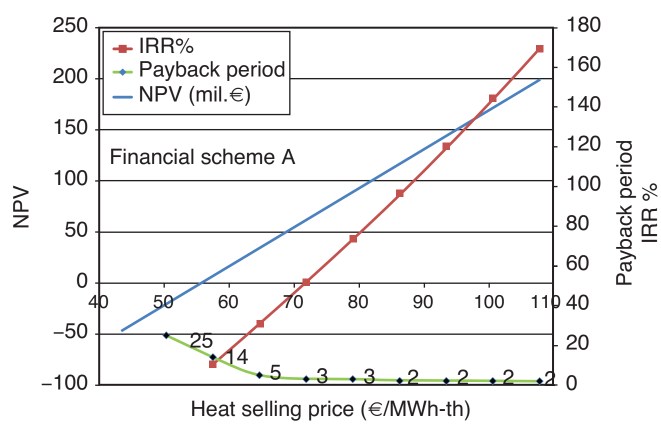

Figure 1: Sensitivity analysis regarding heat selling price (K1: Natural gas boiler).

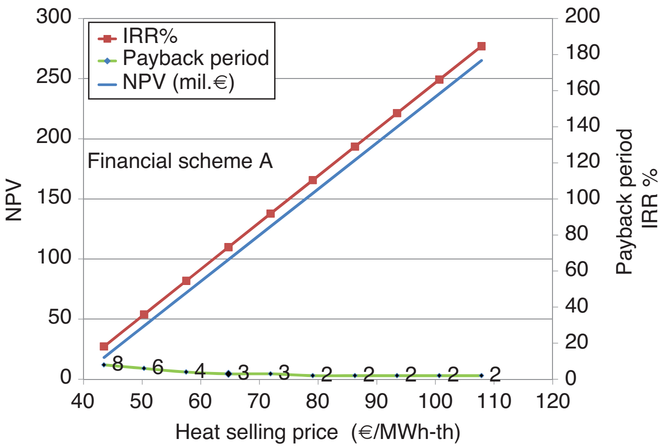

Figure 2: Sensitivity analysis regarding heat selling price (K3: Biomass boilers).

For scenario K3 – Biomass boilers, the results of the analysis showed that in case of an increase in price of biomass up to 5%, the investment is sustainable with IRR above 12%. In the opposite case of price reduction of biomass, the investment is getting of course even better.

3.2. DH network of Ptolemaida

3.2.1. Technical layout - optimal thermodynamic cycle

Based on the technical demands presented in paragraph 2.2 and on the technical specifications of the major components (boiler, turbogenerator set, heat exchangers for heat recovery) as provided by manufacturers' tenders, the optimal thermodynamic cycle configuration, in terms of (primarily) electrical and (secondarily) thermal efficiency, was elaborated and is presented in Figure 3. The plant's layout was simulated with the process simulation software IPSEpro [14].

The basic equipment consists of the thermal oil Boiler, the power generation circuit (ORC) and the district heating section (i.e. the interface between the ORC and the DH network).

The thermal oil Boiler circuit uses Solutia Therminol 68 as heat transfer fluid from Boiler to ORC and is composed of a High Temperature thermal oil loop 260/315 °C and a Low Temperature thermal oil loop 155/260 °C. It also includes exhaust gas - thermal oil heat exchangers, a Biomass Combustor and an Air Preheater with exhaust gas (LUVO).

The Power generation circuit (ORC) uses Silicone Oil (MDM) as organic working fluid and comprises thermal oil - organic fluid heat exchangers, an organic fluid Turbine (with inlet/outlet operational parameters: 6 bar + 248 °C / 0.23 bar + 217 °C), an asynchronous Generator 999 kWel and a Recuperator.

The DH section (i.e. the interface between the ORC and the DH network) includes a water – cooled condenser exploiting turbine outflow for the DH demands in wintertime and an air – cooled condenser for the surplus heat in summertime or in wintertime partial load demand.

The main results of the plant's heat balance are summarized in Table 6.

Table 5: Sensitivity analysis regarding cost of biomass for scenarios K2: Biomass CHP and K3: Biomass boilers.

		K2 - Biomass CHP			K3 - Biomass boilers		
		Financing scheme A					
	Cost of biomass (€ /MWh-th)	NPV (€)	Payback period (years)	IRR (%)	NPV (€)	Payback period (years)	IRR (%)
20%	37.61	–2.10 mil. €	>25	4.72	–8.07 mil. €	>25	–2.02
15%	36.04	20.68 mil. €	18	7.68	–1.50 mil. €	>25	3.82
10%	34.47	43.45 mil. €	14	10.54	5.07 mil. €	17	8.80
5%	32.91	66.08 mil. €	11	13.34	11.59 mil. €	10	13.49
0%	**31.34**	**88.85 mil. €**	**9**	**16.15**	**18.16 mil. €**	**8**	**18.18**
–5%	29.77	111.62 mil. €	7	18.97	24.73 mil. €	6	22.95
–10%	28.21	134.25 mil. €	6	21.80	31.25 mil. €	5	27.82
–15%	26.64	157.02 mil. €	6	24.69	37.82 mil. €	4	32.88
–20%	25.07	179.80 mil. €	5	27.63	44.39 mil. €	4	38.09

Heat selling price equal to 43.50 €/MWh-th

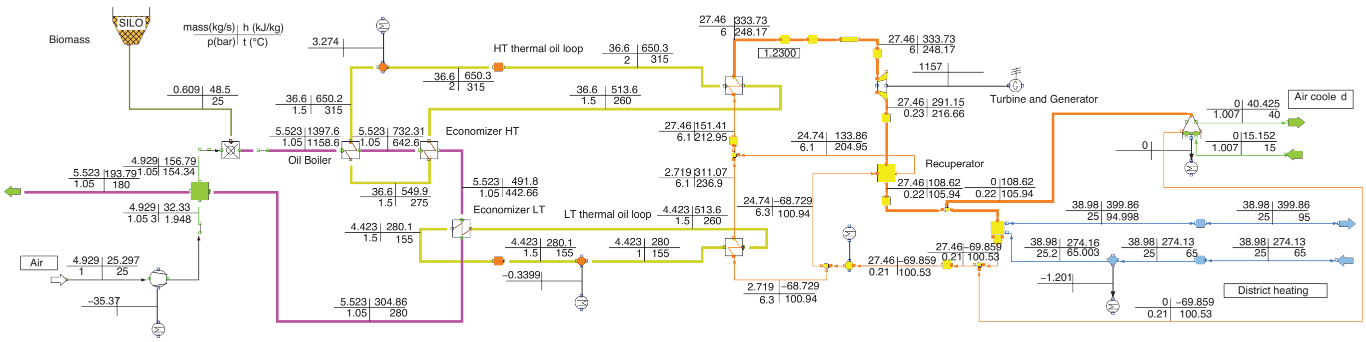

Figure 3: Heat & Mass Balance Diagram.

Table 6: Overall heat balance results.

		Value	Unit
Fuel	Biomass mixture consumption	2.19	t/h
	Wood chips consumption	1.88	t/h
	Straw consumption	0.31	t/h
	Biomass mixture heat input	6.94	MWth
Power	Net power	0.99	MWel
	Net electric efficiency	14.39	%
DH	Useful thermal output	4.90	MWth
	Thermal efficiency	70.62	%
	DH water mass flow rate	38.98	Kg/sec

3.2.2. Economic evaluation

Based on the techno economic data and assumptions of paragraph 2.2 and the technical results of paragraph 3.2.1, the overall investment indices are deduced and presented in Table 7, while Figure 4 depicts the evolution of the cumulative discounted cash flow over time.

Therefore this is a moderately profitable investment, eligible to JESSICA (Joint European Support for Sustainable Investment in City Areas, [20]) funding mechanism. The application that Ptolemaida DH Company submitted for entering JESSICA included the financing scheme of Table 8, which results in a quite profitable investment.

Table 7: Investment indices.

Parameter	Value	Unit
NPV	639.28	thousand €
IRR	11.64	%
Payback period	12.3	years

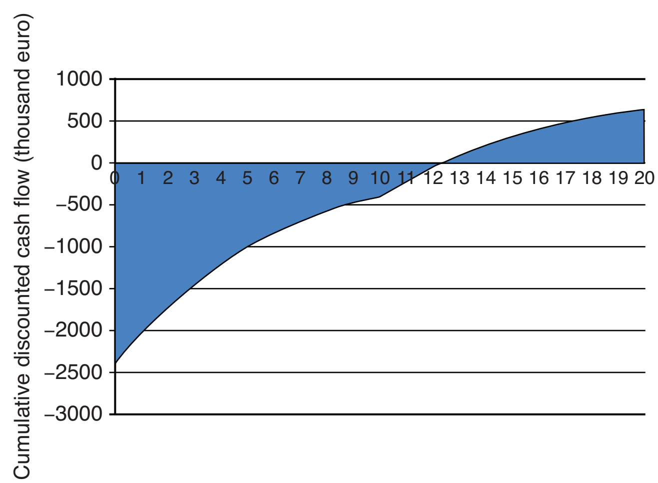

Figure 4: Investment evolution over the years.

4. Discussion

Recently in Greece, the Ministry of Environment, Energy & Climate Change (YPEKA) published (7/3/2014) a Bill entitled "Provisions on the

Table 8: Financing scheme and new investment indices with JESSICA.

Parameter	Value	Unit
Financing scheme with JESSICA		
Own capital	20	%
Subsidy	**0**	**%**
Bank loan	10	%
JESSICA loan	70	%
Bank loan interest	8	%
Bank loan duration	10	years
JESSICA loan interest	3	%
JESSICA loan duration	10	years
Investment indices with JESSICA		
Parameter	**Value**	**Unit**
NPV	1,407.79	thousand €
IRR	21,92	%
Payback period	5.5	years

rectification of the Special Account of article 40 of law 2773/1999 and other provisions" [21]. According to this, a review of FITs for electric power from operating RES and Cogeneration stations is foreseen. In the Table 9 the new FIT values are presented.

4.1. Impact on Kozani CHP plant

Based on these changes, scenario K2: Biomass CHP must be reviewed, in order to see how the investment is affected by the change of the selling price of electricity. The old FIT was 150 €/MWh-el and according to the new deal is reduced by 10%.

The effect of this change is summarized in Table 10. It is noticed that the investment is no more profitable for DH Company of Kozani, presenting an IRR lower than 12% and a higher payback period in relation to the previous FIT.

Moreover, the selling price of thermal energy for which the IRR is set to 12%, was determined. For financial scheme A, the selling price of thermal energy for which IRR takes the value of 12% is 48.25 €/MWh-th. This means a price increase of 10.92% compared with the current price (43.50 €/MWh-th). For financial scheme B, the selling price of thermal energy for which IRR takes the value of 12% is 49.68 €/MWh-th. This means a price increase of 14.21% compared with the current price (43.50 €/MWh-th).

4.2. Impact on Ptolemaida CHP plant.

The impact of the new FIT (198 €/MWh-el instead of the so far applied one, i.e. 230 €/MWh-el) on the investment of Ptolemaida's CHP plant (with the financing scheme of Table 8) is shown in Table 11.

Thus, the investment is damaging under the current circumstances. In order for the investment to become profitable it is essential that a State subsidy is provided, e.g in the context of the forthcoming Partnership Agreement [22], although the subsidy will entail an even lower FIT (i.e. 180€ /MWh-el). By keeping constant own capital and bank loan portions, the economic analysis was focused on the magnitude of the necessary subsidy and it was deduced that a subsidy of at least

Table 9: Latest review of FIT values for CHP stations.

	CurrentFIT (€/MWh-el)	New FIT (€/MWh-el)	Variation (%)
CHP Biomass ≥ 5 MW	150	**135**	−10.0
CHP biomass ≤ 1 MW	230	**198**	−13.9

Table 10: Effect of new FIT in scenario K2: Biomass CHP.

FIT (€/MWh-el)	NPV (€)	IRR (%)	Payback period (years)
		Loan 25% (A scheme)	
150	88.85 mil. €	16.15	9
135	36.33 mil. €	9.76	16
		Loan 15% (B scheme)	
150	92.60 mil. €	14.89	9
135	40.01 mil. €	9.55	15

Table 11: Investment indices with New Deal's FIT.

Parameter	Value	Unit
NPV	–516.89	thousand €
IRR	1.87	%
Payback Period	–	

being studied to cover the future thermal load can potentially become viable. Scenario K1 with natural gas boiler seems unattractive since an increase in heat selling price above 33% is required in order to become viable. Moreover, a reduction up to 20% of natural gas cost won't have any significant effect regarding sustainability of the project.

Table 12: Financing scheme and investment indices with 40% subsidy and JESSICA.

Parameter	Value	Unit
	Financing scheme with Subsidy and JESSICA	
Own Capital	20	%
Subsidy	**40**	**%**
Bank loan	10	%
JESSICA loan	30	%
Bank loan interest	8	%
Bank loan duration	10	years
JESSICA loan interest	3	%
JESSICA loan duration	10	years
	Investment indices with Subsidy and JESSICA	
Parameter	**Value**	**Unit**
NPV	206.15	thousand €
IRR	11.85	%
Payback period	10.6	years

40% is needed in order for the investment to become satisfactorily profitable. Such a financing scheme is presented and the corresponding overall investment indices are shown in Table 12.

5. Conclusion & outlook

Introduction of RES in DH system of Greece has much potential but each scenario must be carefully evaluated in terms of feasibility before final implementation. Regarding DH system of Kozani, the results of the economic evaluation indicated that all three scenarios

Scenario K2 with biomass CHP, although it's a high cost investment, can be profitable with an IRR above 12% even in the worst case that cost of biomass is increased by 5%. However, if the new, lower FIT is applied (135 €/MWh-el), then the investment becomes unattractive with IRR lower than 12% and high payback period (above 15 years). In this case, in order for the investment to become satisfactorily profitable, an increase of the heat selling price at least 10.92% (48.25 €/MWh-th) is required.

As far as scenario K3 with biomass boiler (only for heat) is concerned, it is considered a good alternative for

DH system of Kozani, because it's a low cost investment and remains profitable even in the case that biomass price is increased up to 5%.

Finally, CHP plant for DH system in Ptolemaida seems a promising investment especially when using the JESSICA funding mechanism (IRR = 21.92%, payback period of 5.5 years). Unfortunately, the impact on this investment is high under the current circumstances and the new FIT to be applied. In this case, in order for the investment to become satisfactorily profitable, a subsidy of at least 40% is required (IRR = 11.85%, payback period of 10.6 years).

In conclusion, introduction of RES in DH system of Greece is a challenging task that DH operators have to manage in the future in order to increase the low carbon heat production. This task is getting even more difficult when country's economic conditions and motivation for development of RES are highly unstable. Therefore, the DH operators need to be always ready to use several financial tools, such as JESSICA or/and a State subsidy, being at the same time prepared for a possible change in their pricing policy (e.g. increase in the heat selling price). Finally, they need to bear in mind a potential modification of their initial technical planning in order to reduce the risk, e.g. by going from the CHP option to a solely thermal production option so as to decrease the CAPEX, in case electricity FITs are no more favorable.

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Abbreviations

ar:	as received
CAPEX:	Capital Expenditure
CHP:	Combined Heat & Power
daf:	dry and ash free
DH:	District Heating
FIT:	Feed in Tariff
GTCC:	Gas Turbine Combined Cycle
IRR:	Internal Rate of Return
JESSICA:	Joint European Support for Sustainable Investmentin City Areas
LCA:	Life Cycle Analysis
NPV:	Net Present Value
NGCC:	Natural Gas Combined Cycle
O&M:	Operations & Maintenance
ORC:	Organic Rankine Cycle
RES:	Renewable Energy Sources
VAT:	Value Added Tax

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