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Economic evaluation of biomass heating systems: a case of greenhouses in northern Greece

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Abstract

In this paper, a methodology for the evaluation of the economic viability of investment plans for biomass heating systems is applied. The factors participating in the development and application of biomass heating systems as well as the financial criteria used for the evaluation of the investment are analytically presented. The methodology is applied to the economic evaluation of two greenhouse-heating projects in the area of Chalkidiki, northern Greece.

Keywords: Biomass, Heat Production, Evaluation Model, Financing Schemes, Sensitivity Analysis, Internal Rate of Return, Net Present Value.

1. Introduction

The new favourable conditions shaped during the last few years both on a European and a national level (new legislative framework, E.U. Support Frame for Energy, CO_2 emissions mitigation programme) have offered important prospects for the utilization of Renewable Energy Sources (RES) in Greece. These prospects are reinforced by the ascertained existence of a rich potential, which enables support of a RES policy both flexible and continuable. An important aspect of RES with particularly interesting future prospects is that of biomass energy utilization, which can take many forms. The most widespread energy use, and at the same time the one having the most important potential for expansion in the future, is the production of heating energy for the supply of either heating processes in the industrial sector or for buildings heating.

In the agricultural sector in particular, besides the use of wood as a heating means for farm houses (fireplaces, wood stoves, etc.), energy derived by the use of biomass was always used for greenhouses heating, the dehydration of products (e.g. sunraisins), or the production of lime by direct burning of agricultural residues. This type of biomass use resolves chronical issues that are raised with waste disposal.

An extensive report on the characteristics, origin and possible biomass utilization is given in [Kodosakis, (1994)]. An analytic description of direct burning technologies, which are more closely related with heating systems and therefore our particular area of study, is presented in [CRES, (2001)]. In [Tsigas, (1997)], it is presented the way that waste heat recovery systems (WHR) operate, while in [Papakostas, 1999] emphasis is given on the potential cooperation of heat pumps and burners. The basic characteristics of combined heat and electricity production systems, which constitute an economically sound solution of bioenergy use, with a rather high efficiency rate, are described in [HACHP, (2005)]. In [Soldatos P. and Lychnaras V., (2003)] and [Madlener R. and Myle, H., (2000)] there is an extensive presentation of models pertaining to the energy utilization of biomass and a general illustration of the multi-level research on the conditions under which biomass utilization is best improved.

In this paper, a methodology is applied for evaluating investment plans pertaining to the installation of biomass heating systems. This methodology examines a project both from technical and economic aspect. The procedure includes calculation of the heating demands, capacity determination, district heating systems planning and the calculation of annual savings in relation to a conventional fuel heating system. Apart from the analytical listing of all expenses accompanying a biomass system installation, the methodology approaches the project as an investment, examining its efficiency for the entire project life, taking under consideration a number of financial parameters and the time value of money.

An additional characteristic of the methodology presented is that it enables one to calculate the total mitigation of gas emission – which contributes to the greenhouse effect – thanks to biomass systems use. The quantities of those gases are calculated as equivalent amounts of carbon dioxide emissions.

The structure of the paper is as follows: the structure and components of a biomass heating system are described in Section 2, while the model of economic evaluation of such an installation is presented in Section 3. In Section 4, the model is applied to the evaluation of two greenhouse-heating projects in Chalkidiki. In Section 5, conclusions are drawn.

2. *Biomass heating systems*

Biomass heating systems burn plant or other organic matter - such as wood chips, agricultural residues or even municipal waste - to generate heat. This heat can be transported and used wherever it is needed - for the ventilation and space heating requirements of buildings or whole communities, or for industrial processes. Biomass heating systems differ from conventional wood-burning stoves and fireplaces in that they typically control the mix of air and fuel in order to maximize efficiency and minimize emissions, and they include a heat distribution system to transport heat from the site of combustion to the heat load. Many biomass heating systems incorporate a sophisticated automatic fuel handling system.

Biomass heating systems consist of a number of elements, including a heating plant, which typically includes an automated biomass combustion system and a peak load and back-up heating system, a heat distribution system, and a biomass fuel supply operation. The system can also include a waste heat recovery system from a process or electricity generation unit.

2.1 Biomass combustion system

In the Biomass Combustion System (BCS), the principal interest in a heating plant, the biomass fuel or feedstock moves through the BCS in a number of stages, many of which are illustrated in ***Figure 1*** and described here [NRCan, (2002) & (2005)]:

Biomass Fuel (Feedstock) Storage: the biomass fuel in the storage area must be sufficient to fire the plant over the longest interval between deliveries. The fuel can be stored in an outdoor pile, a protective shed, or inside a bin or silo. Outdoor storage, though inexpensive, permits precipitation and dirt to contaminate feedstock.

Biomass Fuel (Feedstock) Reclaim: this refers to the movement of the biomass fuel from storage to the combustion chamber. It can be effected manually, as in the loading of outdoor furnaces with cut logs; fully automated, using augers or conveyors; or rely on both operator and machinery. Fully automatic systems can be vulnerable to biomass fuel variability and detritus, such as frozen or irregularly shaped clumps, wire, or gloves.

Biomass Fuel (Feedstock) Transfer: this is the movement of the biomass fuel into the combustion chamber. In automated systems, a screw auger or similar device moves the biomass fuel and a metering bin measures the flow into the combustion chamber.

Combustion Chamber: the biomass fuel is injected into an enclosed combustion chamber, where it burns under controlled conditions. To this end, a control system regulates the inflow of air in response to heat demand; in automated BCSs, biomass fuel flow is also regulated. Refractory materials keep the heat of combustion inside the chamber. Many combustion chambers support the burning feedstock on a grate, enabling airflow up through and over the burning biomass fuel, facilitating complete combustion. In more sophisticated systems, the grate moves in order to evenly distribute the fire bed, convey the biomass fuel through zones of different under-fire airflow, and to push the ash to the end of the combustion chamber. Hot exhaust gases exit the combustion chamber and either pass through a heat exchanger, into a secondary combustion chamber containing a heat exchanger, or, if the heat exchanger is in or around the combustion chamber, directly into an exhaust system.

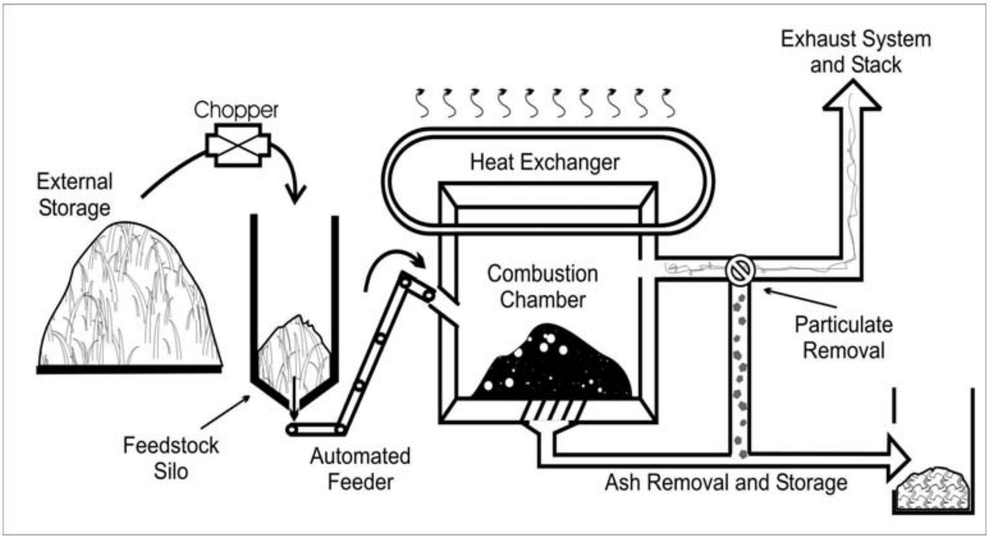

Figure 1: *General layout of a biomass combustion system*

Heat Exchanger: the heat from combustion is transferred to the heat distribution system via a heat exchanger. In simple outdoor furnaces, an insulated water jacket around the combustion chamber serves as the heat exchanger. Larger BCSs use boilers, with water, steam, or thermal oil as the heat transfer medium.

Ash Removal and Storage: this involves voiding the BCS of bottom ash, which remains in the combustion chamber, and fly ash, which is transported by the exhaust gases. Bottom ash may be removed manually or automatically, depending on the system. Fly ash may deposit in the secondary combustion chamber or the heat exchanger (necessitating cleaning), escape out the flue, or be taken out of suspension by a particulate collection device (exhaust scrubber).

Exhaust System and Stack: this vents the spent combustion gases to the atmosphere. Small systems use the natural draft resulting from the buoyancy of the warm exhaust; larger systems rely on the fans feeding air into the combustion chamber to push out the exhaust gases, or draw the exhaust gases out with a fan at the base of the chimney. In addition to the equipment described above, instrumentation and control systems of varying sophistication oversee the operation of a BCS, modulate the feed of air and, in automated BCSs, fuel, in response to demand, and maintain safe operating conditions.

3. *Biomass heating economic evaluation model*

The methodology presented in this paper can be used to evaluate energy production, life cycle costs and mitigation of greenhouse gasses emission for biomass heating installations and/or a waste heat recovery system. The model has been designed to analyse a broad spectrum of applications, from installations in a large scale such as district heating, to individual applications in residential or industrial sector.

The evaluation of the biomass heating project (*alternative heating system* from now on) is carried out in comparison to an existing or a potential heating system using fossil fuel or electricity produced by fossil fuel (*conventional heating system* from now on).

To realize the evaluation, a series of technical elements and economic figures is necessary, based on which we shall determine whether the installation of a biomass heating system instead of a conventional fuel system is financially beneficial. In the first stage, we study the technological aspect of the investment where the existing conventional system is analysed and the alternative one is designed so that it fulfills energy supply requirements. Then, after appraising the costs and benefits of each system, a series of economic indexes is calculated, based on which the investment's efficiency is assessed.

3.1 Models main parameters

The main input data required are listed below:

3.1.1 Site conditions

- Heating design temperature
- Monthly heating degree days below 18°C
- Domestic hot water heating base demand
- Heated floor area
- Heating load

This input data is used to estimate the heating energy demand and the peak heating load.

3.1.2 Base Case Heating System characteristics

- Heating fuel type(s)
- Heating system seasonal efficiency
- Unit cost of fuel

This input data is used to estimate the fuel cost of the existing (conventional) heating system.

3.1.3 District heating network

- Design supply/return temperature
- Length of pipe sections

- Use of transfer stations
- Unit costs of pipes and transfer stations

This input data is used to estimate the pipe size of the distribution lines (based on the heating loads) and the cost of the district heating network.

3.1.4 Renewable Energy System characteristics

- System type(s)
- Capacity
- Efficiency
- Moisture content on a wet basis of biomass

This input is used to estimate the percentage of the annual heating energy demand and percentage of the peak heating load that can be supplied by the renewable energy heating system. In general, the heating system may consist by a *Waste Heat Recovery* system (WHR) or a *Biomass* system or *WHR* and *Biomass* systems combined. Furthermore, it may include a *Peak Load* system to meet a small portion of the annual energy demand during peak heating periods. The *Peak Load* system may consume either fossil fuel or biomass. Finally, provisions are made for the use of a back-up system in case of system shutdown or because of an interruption in the biomass fuel supply.

3.1.5 Initial, annual, periodic costs (or credits)

The most significant initial costs of a project concern costs for project development, engineering, purchase and installation of the renewable energy equipment. The annual costs associated with the operation of a biomass and/or WHR heating system include costs for biomass fuel, peak load fuel oil and parasitic electricity consumption. In addition, property taxes, insurance, spare parts, O&M labour and general and administrative expenses could also be incurred. Periodic cost represents recurrent costs that must be incurred at regular intervals to maintain the project in working condition.

3.1.6 Financial parameters

- Energy cost escalation rate
- Inflation
- Discount rate
- Project life
- Debt ratio/Debt interest rate/Debt term
- Income tax analysis

This input data is used to evaluate the financial viability of the biomass project under alternative financing scenarios.

3.2 Economic evaluation

The economic evaluation takes place for the expected years of the plant's operation in which cash flows (incomes and outcomes) occur. The difference of the total income minus the total costs shows the net fiscal flows of the project, to which the financial criteria are applied. It should be noted that in the following criteria wherever the term 'initial costs' is used, it refers exclusively to the amount, $I_{cap,}$ which the investor(s) contribute(s) to the project (own funds).

The economic evaluation of the biomass heating project is evaluated through five financial criteria:

3.2.1 Net Present Value (NPV)

Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows associated with an investment project. In order to calculate the NPV of a project, the use of a discount rate, k, is needed. The discount rate is the rate of an alternative safe investment where the capital investments of the project, I_{cap}, could be invested. The discount rate is compared with the internal rate of return (IRR) of the investigated project. The NPV is calculated by [Zopounidis, (2000)]:

$$NPV = \sum_{t}^{PL} C_t \cdot (1+k)^{-t} - I_{cap} \qquad \textbf{(1)}$$

where $\boldsymbol{C_t}$ is the net cash flow of the project at year **t** and ***PL*** is the expected lifetime of the project.

3.2.2 Internal Rate of Return (IRR)

The IRR expresses the amount of income and other benefits of the plant, expressed in a percentage of the annual initial cost reimbursement of the latter. Technically, IRR is a discount rate: the rate at which the present value of a series of investments is equal to the present value of the returns on those investments. As such, it can be found not only for equal, periodic investments but for any series of investments and returns. The larger IRR an investment has, the more profitable it is considered to be.

3.2.3 Year-to-positive cash flow

It is the time when the first positive net cash flow occurs. In the case of this measurement, the cash flows are examined until the first net positive cash flow is found. In many cases, the first positive net cash flow occurs between two sequential years; therefore, the calculation of the exact time of the first positive net cash flow occurrence is defined by using linear interpolation between those two years.

3.2.4 Simple Payback

This measurement represents the length of time that it takes for an investment project to recoup its own initial cost, out of the cash receipts it generates. The time counts from year 0. The payback time is calculated by:

$$SP = \frac{I_{cap} - I_G}{p - E_{yr}} \qquad \textbf{(2)}$$

where $\boldsymbol{I_{cap}}$ are the capital investments of the project, $\boldsymbol{I_G}$ are the grants to the project, $\boldsymbol{p}$ are the annual savings of the project and $\boldsymbol{E_{yr}}$ is the annual operating cost of the project (the total annual costs excluding debt payments). Although the Simple Payback method does not consider the time value of money, it is a useful indicator to indicate the level of risk of an investment.

3.2.5 Profitability Index

This indicator represents the comparison between the project's NPV with the capital investments of it, $\boldsymbol{I_{cap}}$:

$$PI = NPV / \mathrm{I}_{cap} \qquad \textbf{(3)}$$

This criterion shows the performance of the investigated project and is an expression of the relative profitability of the project. Positive ratios are indicative of profitable projects. As PI increases over 1.0, so does the financial attractiveness of the proposed project.

4. Application of the financial evaluation model

In this Section, we examine two investment plans of applying biomass systems for greenhouse heating. This sector has been particularly developed during the past twenty years in Greece and an important number of greenhouses are already heated by biomass combustion. The utilization of agricultural waste products for heat production can have several economic benefits for both the producer and the local economy.

The existing biomass applications concern mainly the heating of small- to medium- (2-5 acres) size greenhouses, which comprise the majority of those used in Greece. As a rule, the biomass is derived from waste products of the greenhouse itself or agricultural and forest waste of the surrounding area and is supplied at a very low cost or even at zero cost.

In this paper, two applications of energy utilization of biomass for small- and medium- sized greenhouses heating, will be examined and the conditions under which those investments are economically acceptable will be examined. The tomato production greenhouses are located at Lakoma area of lowland Chalkidiki. The producers of the area have no biomass deposits of their own; but they can ensure a steady supply of significant quantities of biomass (products of pruning, mainly of olive trees and vines) after an agreement with the local farmers association. They have, however, to shoulder the cost of collection and transport of the prunings from their production sites, which are scattered in the surrounding area – and some of them in distant locations. This cost, which includes the expenses of collection machinery, transport truck, cutting procedure and surely some labour charges, is very difficult to estimate. Therefore, this factor must be included in the sensitivity analysis, so that we can pinpoint the maximum amount that can be set aside for the biomass to be procurred in order for the investment to be economically viable.

Tomato greenhouses demand a stable temperature of 18 ^{o}C annualy and humidity levels of 75%.

The development and evaluation of the above two investment plans follows the methodology given in Section 3 of the present paper.

4.1 Problem description

The two projects being studied here have some basic characteristics in common. They are situated in the same location (Lakoma, Chalkidiki) and therefore have common climatological data. They concern same-type greenhouses (both fitted with polyethylene sheets), yielding the same production (tomato) and therefore the heating loads are the same. Finally, in both cases we have the substitution of diesel fuel same-efficiency systems with the same type of biomass fuel.

Project I: A tomato producer in Chalkidiki heats, for the time being, his 5-acre greenhouse with diesel which he gets for €0.40/L. For economic reasons, he is thinking of installing a biomass heating system to meet the heating demands of the greenhouse and he can afford to spend up to €60,000.00. Given that the biomass supply cost is unknown, he has asked to examine whether, and under which conditions, his investment will be profitable.

Project II: The same producer suggests to the owner of the adjacent greenhouse, which has exactly the same characteristics but is bigger in size, that they should install a common biomass system. The two greenhouses are contiguous; therefore the biomass system could be installed between them and in close proximity to both of them so that no special custom fittings and extensions would be demanded in the existing distribution piping. In the following, this case shall be examined as a single greenhouse of such an area as that of the total of the two greenhouses.

4.2 Development and structure of the study

To begin with, both projects will be developed in common, and their characteristics and data will be presented in parallel, in order to have a direct comparison of the results. After calculating the heating demands of each project, based on the climatological constants of the area and the heating loads of the greenhouses, the biomass systems capacity will be sized. Then, based on system efficiencies (conventional/alternative) and the heating values of the fuels in use (diesel/biomass), the annual consumption of each heating system will be calculated.

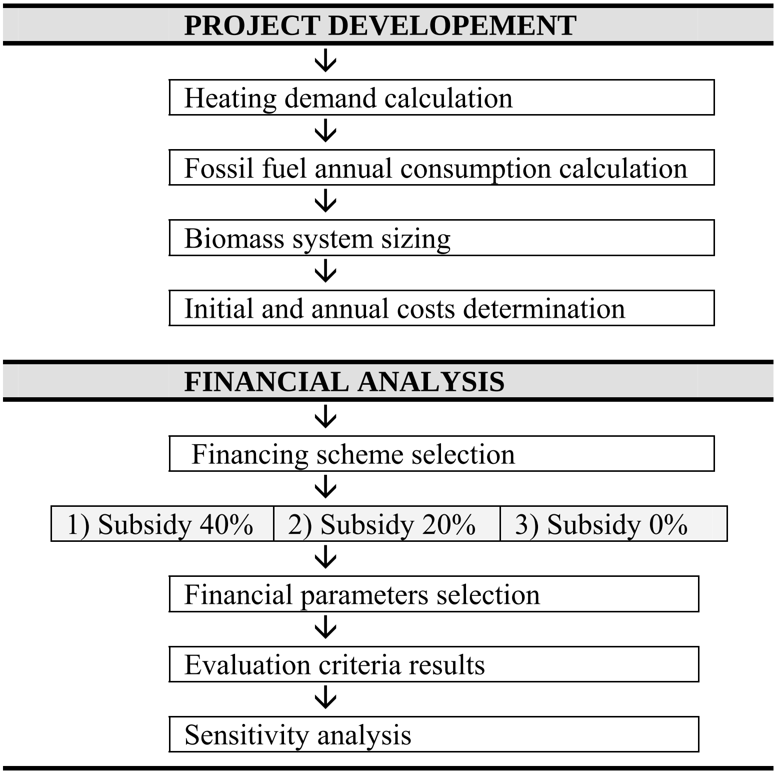

***Figure 2**: Techno-economic study flow chart*

The economic analysis for each project will be conducted separately. The values of the parameters presented in Table 5 are part of the Basic Scenario for each project. Then a sensitivity analysis for the values of the Basic Scenario (for each project) will be conducted, while two alternative financing scenarios (Scenario A & B) will be examined. Figure 2 shows the flow diagram of the project study.

4.3 System design input data

4.3.1 Greenhouse(s) Heating Load

The maximum capacity for maintaining the temperature to an even 18 °C in a greenhouse is 170W/m^2 [Kittas et Al., (2002]. In reality, it is very seldom that a producer seeks to maintain a temperature of 18 °C during the cold winter months. However, we have selected this value for the load so that the temperature requirements of cultivation will be fully met.

4.3.2 Biomass fuel type

The biomass designated as fuel comes from local agricultural waste products, mainly olive tree prunings. The value of their moisture content is estimated at 35%. Their calorific value on a dry basis has been found to be equal to 3,896kcal/kg or 16.30MJ/t.

***Table 1**: Main input data for the installation design*

Project name:	***Lakoma I***	***Lakoma II***
Greenhouse		
Heated floor area	5,000 m^2	11,000 m^2
Heating load	170 W/m^2	170 W/m^2
Unit cost of fuel (diesel)	0.40€/L	0.40€/L
Biomass System	*Heating*	*Heating*
Boiler capacity	900 kW	2,000 kW
Seasonal efficiency	80%	80%
Moisture content of biomass	35%	35%

***Table 2**: Main output data for the installation design*

Project name:	***Lakoma I***	***Lakoma II***
Annual energy demand		
Peak heating load	850 kW	1,870 kW
Heating energy demand	1,519 MWh	3,342 MWh
Annual fuel consumption/ requirement		
Diesel	217,583 L	478,683 L
Biomass requirement	746 t	1,641 t

4.3.3 Biomass system(s) capacity

The biomass systems capacity for each project was selected after calculating the heating demands of each greenhouse and determining the minimum capacity of the biomass boiler that satisfies the peak load of each installation. This happens when the biomass boiler has actual capacity at least equal to the peak load of the installation (850 kW for *Project I* and 1,870 kW *for Project II*). Biomass systems of this size are made to order. System capacity was decided to be 900kW for the first project and 2MW for the second.

In both cases, the greenhouse heating distribution system is going to need neither replacement nor extension. The biomass burner will replace the conventional diesel burner and will be connected to the existing, low temperature, greenhouse heating distribution system. The conversion of the connection mode necessitates no special expense.

Tables 1 and 2 show the main parameters that concern the installation design of each project.

4.4 Economic investigation

Systems that burn woodchips (2-3cm long) are much cheaper than those that burn large pieces of wood. The difference in their price is much larger than the cost of buying a new chopper for biomass fuel, whose cost can amount to €12,000.

The cost for a wood chips biomass system of 900kW capacity is up to €175,500.00 (*Project I*), while for a 2MW capacity system it can be up to €350,000.00 (*Project II*). Both prices include buying, transportation and installation of the systems with all the relevant equipment (feed silos, electrical installation, control system, etc).

It is also required to construct a building to house the system and a shed where the chipped supplies of biomass will be kept. The shed will have a concrete sloping floor while the sides and the roof will be constructed out of corrugated iron. For *Project II,* the total area of the buildings will be 264 m^2, with construction cost of 250€/m^2, namely €66,000.00; the construction of a 200 m^2 shed will also be required, while for *Project I* the size of the shed can be smaller, given that the required biomass quantity – and therefore the required storage space – is smaller. The total area of the building infrastructure for *Project I* does not exceed 200 m^2 with construction cost 250€/m^2, that is €50,000.00.

As already mentioned in the introduction, the biomass supply cost is not known. In the initial scenario we provide an **approximate estimation** of biomass price and then we examine the efficiency of the investment for changes in this price.

The cost data for the realisation of both projects are presented in Table 3.

4.5 Financial consideration

In Greece, Renewable Energy Sources projects are subsidized by the E.U. *Support Frameworks* up to 40% of their initial cost depending on the project’s category and size, while the new national law for development makes provisions for subsidies from 40 to 55%.

***Table 3**: Initial and annual costs for each project*

Project name:	***Lakoma I***	***Lakoma II***
Initial Costs		
Biomass system	175,500.00€	350,000.00 €
Chopper	12,000.00€	12,000.00€
Building construction	50,000.00€ (200m^2)	66,000.00€ (264 m^2)
Total:	***237,500.00 €***	***428,000.00 €***
Annual Costs		
Operation cost	1,000.00 €	1,000.00 €
Biomass	37,289.00 € (746 t ·50€/t)	82,036.00 € (1,641 t ·50€/t)
Parasitic electricity(1)	3,200.00 € (32,000kWh)	7,000.00 € (70,000kWh)
Annual Savings		
Diesel consumption	87,033.00 €	191,473.00 €

In the present paper, we shall examine three different financing scenarios for each project. A major factor to determine the financing scheme is the amount of the subsidy the project can receive. Thus, apart from the *Base Case* in which the project is subsidized with 40% of its initial cost, two alternative scenarios – with a 20% subsidy for *Case A* and zero subsidy for *Case B* – shall be examined.

From now on, each project will be examined separately.

4.5.1 Case Study I: Lakoma I

The producer can afford up to 60,000.00 (2) for the investment (own funds) while the rest of the initial cost will be supplied from a bank loan. The producer's available capital is considered given and stable. The three financial schemes examined are determined by the amount of subsidy. The sum of the initial capital and the subsidy does not cover the initial cost of the investment in none of the three cases; therefore the rest of the required capital will be acquired through loan.

[1] The parasitic electricity is the electrical energy required to run the biomass systems' auxilaries such as the fuel feeder, the ventilator, etc.

[2] The amount of 60,000 euros that the farmer affords, is less than the cost of buying a new diesel burner (80,000 euros approx.) given the size of his greenhouse.

Table 4 shows the three financing schemes that will be examined. The criteria based on which each scheme will be examined, have been presented in Section 3.

***Table 4**: Financing schemes for Lakoma I project*

	Project equity	Subsidy	Debt
Base Case	25,2%	40%	34,8%
Case A	25,2%	20%	54,8%
Case B	25,2%	0%	74,8%

The Agricultural Bank of Greece provides investment grants with r_{debt} = 3% interest rate (while the interbank rate for medium-to-long-term grants of other banks is approximately 4.8% (June of 2005)).

The discount rate, based on which the comparison with alternative ways to invest the amount of the initial cost shall be made, has been initially selected to be relatively high, 12%. Besides, the inflation rate has been selected to be 4%, which is 1% above the current inflation (June of 2005).

The financial data are presented in Table 5.

***Table 5:** Financial analysis input data for each of the three financing schemes for Lakoma I project*

Financial parameter	Value	Financial parameter	Value
Energy cost escalation rate	4%	Project life	15 years
Inflation	4%	Debt interest rate	3%
Discount rate	12%	Debt term	12 years

Table 6 presents the results of the financial analysis for the three financing scenarios examined in the study of the project. Based on all evaluation criteria, the project is deemed profitable (*IRR*>*D*, *NPV*>0, *PI*>1) for all possible financial scenarios examined. We should stress here that the above indicators refer not to the farmer's production cycle but the greenhouse heating system.

Having compared the results for the different financing schemes, it is clear that the governmental subsidy provides a great relief from the large burden of the initial cost and should be pursued to its maximum. But even with a reduced subsidy, the replacement of the conventional heating system by a biomass system remains an attractive proposition. In the case of zero subsidies, the investment may still be profitable based on the evaluation criteria but essentially creates a large debt to the bank and has a significantly increased payback period, something which is a decisive factor for the choice of implementing the investment.

***Table 6**: Financial evaluation results for each of the three financing schemes for Lakoma I project*

	Base Case Subsidy = 40%	***Case A*** Subsidy = 20%	***Case B*** Subsidy = 0%
Project equity	59,850.00 €	59,850.00 €	59,850.00 €
Incentives/Grants	95,000.00 €	47,500.00 €	0.00 €
Project debt	82,650.00 €	130,150.00 €	177,650.00 €
Total:	237,500.00 €	237,500.00 €	237,500.00 €
Evaluation criteria	***Evaluation criteria value***		
Internal Rate of Return - IRR	70.0%	62.7%	55.4%
Simple Payback (years)	3.1 yrs	4.2 yrs	5.2 yrs
Year-to-positive cash flow	1.5 yrs	1.7 yrs	2.0 yrs
Net Present value - NPV	285,983.00€	256,424.00€	226,865.00€
Profitability Index - PI	4.78	4.28	3.79

Since the project appears to be profitable in the first case, only worse terms were considered in the sensitivity analysis performed. We should remind here that, since the investment appears to be viable, the object is to determine the crucial price for biomass, over which the project ceases to be efficient.

Lower prices for the diesel were not examined because the selected one (0.4€/L for agricultural usage) is a marginal low price. Any oil price higher than the selected one would definitely lead to the projects greater profitability.

Taking into account the National and European strategies on renewable energy sources, the proportion of the subsidies presents a low degree of uncertainty, so the sensitivity analysis discussed here is for the Basic Scenario only (subsidy 40%).

From the sensitivity analysis, it arises that the financial terms, such as energy cost escalation rate, inflation, debt interest rate and debt term, have an insignificant influence to the projects efficiency; moreover, these parameters have a low degree of uncertainty.

The impact of the discount rate arises when the biomass cost exceeds 94€/ton (IRR is then 12.1%), which is a quite extreme assumption. Anyway, the discount rate would likely be lower than the one we have selected (D=12%), which is marginal high for an investment for agricultural exploitation. If a 9% discount rate is considered (D=9%), the biomass price could climb up to 95.8€/ton (IRR=9.1%).

In case the project's initial cost rises up by 20% (285,000.00€), the investment remains attractive as long as the biomass price does not exceed 85€/ton (IRR>D, NPV>0, PI=1.08), and profitable as long as the biomass price does not exceed 91€/ton (IRR=12.3%, NPV>0, PI=0.29).

The project's life is assumed to be at least 10 years (PL≥10). Even in case that PL=10 (with the debt term also reduced to 10yrs), the project preserves its attractiveness for biomass prices up to 77€/ton (IRR>D, PI=1) and its profitability for biomass prices lower than 88.5€/ton (IRR=D, PI=0).

Greek market experience has shown that the maximum payback period for biomass heating systems is three years. In this particular case, which is the investment of a farmer on his production, we must consider the desired payback period to be smaller than or equal to three years. In the sensitivity analysis carried out, we considered as an extra criterion, that for simple payback values larger than or equal to four years, there might be some skepticism about project implementation.

Table 7 presents the critical values for biomass unit cost. The decision on the investment's realization could be based on three different criteria, depending on the investor's point of view, namely: (i) demand for any positive NPV (IRR>D, PI>0), (ii) demand for a NPV larger than the own funds (PI>1), and (iii) a Simple Payback period less than 4 years (SP<4), which in our case, presupposes that the financial criteria are met. The first column of Table 7 presents some alternatives to the Basic Scenario, discussed before. It should be noted that only one parameter changes every time, while the rest remain the same with the Basic Scenario.

Table 7: *Biomass unit cost critical values for Project I*

	Biomass critical cost, (€/ton)		
Criterion:	***PI>0***	***PI>1***	***SP<4***
Basic Case	94€	84€	63€
Initial cost +20%	91€	82€	54€
PL=10yrs	88€	77€	63€
Case A	89€	80€	48€
Initial cost +20%	85€	76€	35€
PL=10yrs	82€	70€	48€
Case B	84€	76€	32€
Initial cost +20%	80€	71€	16€
PL=10yrs	75€	64€	32€

4.5.2 Case Study II: Lakoma II

We consider that the available initial capital (Project Equity) of each producer is perfectly proportionate to the area of his greenhouse. Thus the total initial available capital comes up to 60,000.00 + (6/5)·60,000.00 = €132,000.00 while the rest of the initial cost will be supplied through a bank loan. The available capital of the producers is considered given and stable. The three financing schemes examined are determined by the amount of the subsidy. The sum of the initial capital and the subsidy do not cover the initial cost of the investment, therefore the rest of the required capital will come from a loan. The three financing schemes examined are presented in Table 8.

The same values of the financial parameters are set as those of Project I. The financial input data are presented in Table 5.

Table 9 presents the results of the financial analysis for the three financing scenarios examined in the study of the project. Based on all evaluation criteria presented in Section 3 of the article, the project is deemed profitable (*IRR*>*D*, *NPV*>0, *PI*>1) for all possible financial scenarios examined, with a definite improvement in payback periods compared with Project I. Same as in the study of Project I, it was considered during the sensitivity analysis that for Simple Payback values ≥4 years, there might be skepticism regarding project implementation.

Table 8*: Financing schemes for Lakoma II project*

	Project equity	**Subsidy**	**Debt**
Base Case	30.8%	40%	29.2%
Case A	30.8%	20%	49.2%
Case B	30.8%	0%	69.2%

Table 9*: Results of the evaluation for each of the three financing schemes for Lakoma II project*

	Base Case Subsidy = 40%	***Case A*** Subsidy = 20%	***Case B*** Subsidy =0%
Project equity	131,738.00 €	131,738.00 €	131,738.00 €
Incentives/Grants	171,200.00 €	85,600.00 €	0.00 €
Project debt	125,062.00 €	210,662.00 €	296,262.00 €
Total:	428,000.00 €	428,000.00 €	428,000.00 €
Evaluation criteria	***Evaluation criteria value***		
Internal Rate of Return - IRR	75.0%	68.9%	62.9%
Simple Payback (years)	2.5 yrs	3.4 yrs	4.2 yrs
Year-to-positive cash flow	1.4 yrs	1.5 yrs	1.7 yrs
Net Present value - NPV	675,238 €	621,963 €	568,700 €
Profitability Index - PI	5.13	4.72	4.32

In this case as well, the most critical parameters influencing the profitability of the project are the initial cost, biomass unit cost, and project life. The critical values for biomass unit cost appear in Table 10.

Table 10: *Biomass unit cost critical values for Project II*

	Biomass critical cost, (€/ton)		
Criterion:	***PI>0***	***PI>1***	***SP<4***
Basic Case	97€	88€	73€
Initial cost +20%	94€	85€	65€
PL=10yrs	92€	80€	73€
Case A	93€	84€	60€
Initial cost +20%	90€	81€	49€
PL=10yrs	87€	75€	59€
Case B	89€	80€	47€
Initial cost +20%	86€	76€	34€
PL=10yrs	82€	70€	47€

4.6 Efficiency of the projects

Within the present legislative framework that provides subsidies to Renewable Energy Resources projects for at least 40% of the initial cost, replacing the conventional heating systems with biomass systems constitutes a very good investment. The great initial cost of biomass combustion systems and their complementary equipment is paid off in a few years by saving on the cost of purchasing conventional fuel. An important factor is the price of biomass when it is not a product of the greenhouse itself. The projects examined in this study are a characteristic case of Greek reality regarding greenhouse heating. Both projects can be highly efficient under the condition that the cost of biomass can be secured at a certain level for a long time.

Given the lack of collection and gathering infrastructure in agricultural regions of the country where agricultural residue is left to rot in the fields, assessing the cost of the procedure has to be based on empirical estimations. However, pruning season is specific and known for each culture. The supply cost should include leasing collection machinery and transport truck along with the necessary labour charges. This cost fluctuates depending on the dispersal of the fields where the collection will take place and their distance from the greenhouse.

The structure of this study is such that the two projects are presented as two alternative investment propositions for the 5-acre greenhouse owner. The question that arises is which plan is the most advantageous. Meaning, is it preferable to install a common biomass system with the adjacent (same cultivation) greenhouse to installing a smaller system for the needs of just his greenhouse?

The results of the evaluation criteria we posed for the study of the two projects are not immediately comparable as they pertain to different capitals. By reducing the debt of *Project II* (unifying the heating systems of the two greenhouses) to each producer, the amount that falls to the 5-acre greenhouse owner's share is € 56,846.00 (*Base Case*). This debt is quite smaller than the one of *Project I* (heating of his greenhouse only). This happens because the two producers will share a large part of the initial expenses, such as the purchase of the chopper and most part of the building infrastructure. Regarding the purchasing of the biomass system, there is no significant discount for the 2MW system in relation to the 900kW. With a simplifying reduction to the cost of biomass systems per kW, it is €195/kW for the 900kW capacity boiler and €175/kW for the 2MW capacity boiler. A better approach, however, of the cost difference comes from reducing the cost of the biomass system to the area to be heated. Thus, for the 5-acre greenhouse owner, this cost is €35,100.00/acre for the 900kW boiler and €31,818.00 for the 2MW boiler. We have to be careful, though, because these values are not indicative of the way the cost of biomass systems is assessed. For larger units (over 4MW), the cost of the systems per unit is impressively reduced.

From the financial analysis it is concluded that *Project II* is a little more advantageous than *Project I* (for the small greenhouse producer). The financial difference, nonetheless, is not that great by itself to dictate the implementation of *Project II*, in which the two producers should have an uneventful cooperation with any consequences a future disagreement that they may have. In any case, it is up to the investor's discretion to decide which project he will choose, as they are both highly profitable. From a financial perspective, *Project II* has a small advantage, but since it differs only a little from *Project I*, the fare of the implemented project will be determined by other factors as well (unrelated to this study), such as each producer's autonomy.

5. Conclusions

This paper presents a methodology of evaluating investment plans for installing solid biomass combustion heating systems. The methodology takes under consideration all the parameters involved in the planning and application of biomass heating systems, both from a technical as well as from a financial perspective. By applying the methodology on the study of a pragmatic, and in accordance to the Greek reality, investment plan, we have endeavored to pinpoint those factors that have the most determining influence on the technical feasibility and economic viability of biomass heating system investments.

In Greece, biomass utilization to meet heating needs is dominated by the traditional heating of houses (with wood), while in the last twenty years there has been intense activity in the industrial sector for the supply of heating works. It should be noted that the cases of biomass utilization that attract most investors' interest is agricultural products' treatment industries as they are at the same time both producers and consumers of the fuel. In the agricultural sector, heating greenhouses by burning farming residue is continually boosted with new installed biomass combustion units.

It is characteristic of biomass systems that their initial cost is very high in comparison to conventional fuel systems. Securing the efficiency of an investment in such a system requires certain conditions. One of those conditions is the long time of the unit's annual operation. This is met when the biomass system is used to produce steam in industrial works, energy production for the heating and chilling (through the use of a chiller) needs of a greenhouse, or when there is a large number of heating energy consumers as in district heating. In general, replacing biomass for conventional fuel is advantageous when there is a possibility of biomass supply at a very low cost, so that the high initial expenses can be counterbalanced and paid off by the savings in the supply of conventional fuel. In cases where the biomass is a by-product of the same cultivation where it is going to be utilized for energy, then pay-off time starts at 8 months, and according to the experience of systems already applied in Greece, it is seldom that it exceeds 3 years.

This paper examines two applications of biomass energy utilization for greenhouse heating, based on the evaluation methodology presented in the paper. The first application concerned the installation of a 900kW biomass combustion unit, to heat a five-acre tomato production greenhouse. The second application examined the installation of a 2MW biomass combustion unit, to concurrently heat two adjacent tomato production greenhouses, of a total area of 11 acres. These cases have been treated as two alternative investment plans of the same producer, who is considering replacing his conventional diesel system that heats his greenhouse with a biomass system and wants to determine whether the installation of a common biomass system with the adjacent greenhouse, which cultivates the same produce, is more advantageous.

Given a subsidy of 40% of the initial cost, which the current legislative framework makes provisions for, for RES projects, and an estimated price of biomass supply at 50 euros per ton, both projects were proved to be highly profitable. The 2MW plant project can payback its initial cost in 4 years even with the biomass supply price having been increased to 73 euros per ton, while for the 900kW plant, the respective payback time is achieved at a biomass maximum cost of 63€/t. Nevertheless, even with the subsidy being reduced in half, the projects remain profitable, although to a lesser degree.

Finally, we have examined the possibility of zero subsidy in which case both investments are no longer attractive since, despite the long-term benefits they can bear, the initial cost is rendered inhibitive for agricultural investments. It should be noted, however, that from a financial perspective, the two projects remain profitable even in this case, but having payback times that reach 1/3 of the total projects' life.

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