ECONOMIC EVALUATION OF A PASSIVE SOLAR GREENHOUSE HEATING SYSTEM IN CRETE, GREECE

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Abstract. The objective of this study is to evaluate economically the passive solar heating system. Data collected from tomato greenhouses in the Agriculture Research Center of Northern Greece was analyzed. For Comparison, two other conventional heating systems were used: the traditional anti-frost system and the diesel-fired furnace system. Models have been constructed to assess each heating method and several approaches of appraisal such as net present value, internal rate of return, benefit/cost ratio and payback period were measured in order to fulfill the assessment. The importance of the passive solar system was revealed not only as an energy-saving method but also as a significant contributor to farmer's income and an appropriate system avoiding the risk of high initial investment, which is generally associated with unconventional systems. Meanwhile, it was indicated that the diesel-fired furnace system is ineffective compared to the passive solar system, this ineffectiveness is particularly due to its high fuel consumption and relatively high initial investment. Finally, sensitivity analysis highlighted the importance of the product price in affecting benefits and indicating that income will increase dramatically with earlier production.
Keywords: *cost-benefit analysis, energy conservation, farm income, renewable energy, stochastic efficiency*

Introduction

Out-of-season production of good quality vegetables, ornamentals, and fruit in greenhouses in the Mediterranean is greatly influenced by energy costs. Tataraki et al. (2018) have stated earlier that the greenhouse heating costs have increased dramatically and the use of other sources of energy in response to escalating costs and occasional scarcities of petroleum shall be investigated (Bustos et al., 2016).

Several heating systems are used in the Mediterranean, it can be generally classified into conventional and non-conventional sources. Conventional sources include: Solid fossil fuels, Oil (fossils), Gas (natural) and Hydraulics. Non-conventional sources include: Solar, Wind, Biomass, Geothermal and Waste and reject energy (Balana et al., 2015).

Methods of investment appraisal which takes into account the time value of money are based on compound interest principles. The Net Present Value (NPV) method involves calculating the present value of a project's cash flows, both positive (inflows) and negative (outflows). Buchholz et al. (2017) defined the NPV of a project as the difference between the present values of its future cash inflows and outflows: all annual cash flows should be discounted to the zero points in time (the start of implementation) at a predetermined discount rate (Gautam et al., 2017).

Another way of using discounted cash flows to measure the overall of a project is to find the discount rate which makes the NPV of the cash flow equal to zero. This

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discount rate is termed the Internal Rate of Return (IRR) and represents the average earning power of the money used in a project over its life (Boardman et al., 2017). Larson and Gray (2013) defined the IRR as the maximum rate of interest that can be paid to finance a project without causing harm to the shareholders.

Besides NPV and IRR, a number of other measures of investment performance are in use, the most common of which is the pay-back period criterion, defined as the period of time by which the investments will be covered by the returns (Boardman et al., 2017). The pay-back period is defined as the length of time required for the stream of cash proceeds produced by an investment to equal the original cash outlay required by the investment (Nowotny et al., 2016).

Dixon et al. (2013) has defined the benefit/cost ratio as the present value of benefits over the present value of the costs. The corresponding decision rule requires that the project is accepted if the benefit/cost ratio is greater than one to compute the benefit/cost ratio, the discount rate must be determined. Dixon et al. (2013) has stated probably the best discount rate is the opportunity cost of capital. Another which is often chosen for the benefit/cost ratio calculation is the borrowing rate for the project. A third rate sometimes suggested is the social rate of return, which may more adequately reflect the time preference of society than does the opportunity cost of capital (Benli, 2013).

Ranking projects or alternatives is an important step in evaluation. Differences occur when two or more appraisal methods may yield differing orderings when applied to the same project. Brigham and Ehrhardt (2013), Boardman et al. (2017) and Johnson and Pfeiffer (2016) have suggested several methods of solving the problem.

According to Dogbe et al. (2013), Break-Even Analysis (BEA) establishes the lowest production and/or sales levels at which a project can operate without endangering its financial viability. In the manual for evaluation of industrial projects (Song et al., 2013), the term Break-Even Point (BEP) is used to indicate a level of operation at which a project yields neither profit nor loss, expressed as a volume of sales revenue.

Dogbe et al. (2013) and Elhag (2016) state that sensitivity analysis may be used in the early stages of project preparation to identify the variables in the estimation for which special care should be taken. According to Elhag (2014) and Boardman et al. (2017), sensitivity analysis consists of varying key parameter values, usually one at a time but sometimes in combination, and assessing the effect of such changes on the central tendency estimate of profitability (or the optimal solution).

In this study, three methods of greenhouse heating, two conventional methods (the Anti-Frost System (AFS) and the Diesel-Fired Furnace System (DFS)) and an unconventional method (the Passive Solar System (PSS)), all of which are used in greenhouses producing off-season tomatoes, were evaluated for production and gross returns, and the magnitude of the benefits provided by such technology, using different approaches of appraisal (net present value, internal rate of return, benefit/cost ratio and pay-back period).

Materials and methods

Data collection

Data are obtained from experiments conducted at the National Agricultural Research Foundation (NAGREF) in the region of Thessaloniki for 3 years started from 2012 and lasted until 2014. The designated study area is a semi-arid Mediterranean environment with a cold variant: the summer is hot and dry; the winter is cold and rainy.

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Production and gross returns

A comparison of production and gross returns were made between the three greenhouses. The output of each greenhouse was the statistical mean of the production of tomatoes for three years (2012-2014). Production and gross returns were estimated for the total area of each greenhouse.

Fuel consumption

Annual fuel consumption was estimated as the average fuel consumption for the three years for each greenhouse for tomatoes and the average of two years for melons for each greenhouse.

Labor costs

Labor costs intervene in this analysis, particularly in the installation cost of the three systems in consideration, and especially for the PSS, which is more time-consuming. It intervenes also in the harvest costs.

Maintenance costs

Maintenance costs apply, especially to the PSS. At the beginning of each season, farmers need to fill the plastic tubes and position them, and later empty them and prepare them for the next season. AFS and DFS also have maintenance costs, but these were considered negligible in the calculations.

Models

The problems were formulated to allow the determination of the NPV as a measure of investment worth and to permit comparisons with investment alternatives. Partial budgeting procedures were used in which values with and without the PSS in the first case and with and without the DFS in the second case were used to calculate the NPV and other economic parameters: IRR, benefit/cost ratio and pay-back period (Udayakumara and Gunawardena, 2018).

Model for evaluating the PSS

Simulation methodology was used to evaluate the worth of the investment under various influences occurring in the Thessaloniki region. Three factors as having a major impact on the production benefits (Levidow et al., 2014) were incorporated into the analysis: (1) recoverable yield, which increases with suitable temperature; (2) fuel consumption, which depends on the type of heating system; (3) price of the crop, which varies over the harvest period, with generally higher prices earlier in the season. Following Boardman et al. (2017), the effect of inflation was ignored by assuming that it acts in the same way on revenues and costs and the effects cancel each other. The specific expression was extracted from that utilized by Elhag (2017) and modified to the needs of the problem:

$$NPV = -\sum_{t=1}^{8} \frac{\frac{[1-(-1)^t] IS_t}{2}}{(1+R)^t} + \sum_{t=1}^{8} AR_t + SF_t - AE_t - MN_t + \frac{IC_1}{(1+R)} + \frac{IC_5}{(1+R)^5} \quad \text{(Eq.1)}$$

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where:
IS_t = purchase price, including the cost of installing the PSS in year t for a 0.1 ha greenhouse;
IC_i and IC_S = purchase price, including the cost of installing the AFS in years one and five for a 0.1 ha greenhouse;
ARt = additional annual returns;
SFt = annual fuel costs saved;
AEt = additional annual harvest costs;
MNt = additional annual maintenance costs;
R = interest rate;
t = year of operation;
where:
$AR = \sum_i^n P_i (Q_{is} - Q_{ic})$;
$SF = H(F_c - F_s)$;
$AF = K(Q_s - Q_c)$;
and where:
Pi = price of the crop on Day i (dr/kg);
Qis = production of greenhouse S on Day i (kg);
Qic = production of greenhouse C on Day i (kg);
H = fuel price (dr/1);
Fc = annual quantity of fuel used in greenhouse C (1);
Fa = annual quantity of fuel used in greenhouse S (1);
K = harvest costs (dr/kg);
Qa = annual production of greenhouse S (kg);
Qc = annual production of greenhouse C (kg);
n = number of harvest days.

Model for evaluating the DFS

This model was similar to that used for the PSS, with certain parameters altered, such as the life of the system and the electricity needed to operate it. The assumptions used for the evaluation of the PSS were also made.

The NPV was determined by considering the monetary flows of the two greenhouses F and C, using the following expression which also extracted from that utilized by Agil and Hosseinian (2014) and modified to the needs of the problem:

$$NPV = \frac{-IF + IC_1}{(1+R)} + \frac{IC_5}{(1+R)^5} + \sum_{t=1}^{8} \frac{AR_t - CF_t - AE_t - EC_t}{(1+R)^t} \quad \text{(Eq.2)}$$

where:
IF = purchase price, including the cost of installing the DFS, for a 0.1 ha greenhouse;
ICi and IC5 = purchase price, including the cost of installing the AFS in years one and five for a 0.1 ha greenhouse;
ARt = additional annual returns;
CFt = additional annual fuel expenses;
AEt = additional annual harvest costs;
ECt = annual electricity consumption by the furnace;
R = interest rate;
t = year of operation;

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where:

$AR = \sum_i^n P_i (Q_{iF} - Q_{iC})$;

$CF = H(F_F - F_c)$;

$AF = K(Q_F - Q_C)$;

and where:

Pi = price of the crop on Day i (dr/kg);
QiK = production of greenhouse F on Day i (kg)
Qic = production of greenhouse C on Day i (kg)
H = fuel price (dr/1);
Ff = annual quantity of fuel used in greenhouse F (1);
Fc = annual quantity of fuel used in greenhouse C (1);
K = harvest costs (dr/kg);
Qf = annual production of greenhouse F (Kg);
Qc = annual production of greenhouse C (kg);
n = number of harvest days.

Results

Evaluation of the PSS

Variables used in the evaluation of the PSS with no distinction between varieties are depicted in *Table 1*. This evaluation is based on the application of the model which gives the NPV. Interest is high in Greece: an annual rate of 20% was assumed (R = 0.2). An assisted computer program was used for financial analysis; the application of the discount cash flow approach is illustrated in *Table 2*.

NPV

The formal selection criterion for NPV is to accept all investments with a positive NPV. The use of the PSS, over an 8-year period, produced an NPV of almost 5,500.0 euro, indicating a significant increase in earnings of greenhouse farmers and a contribution to energy saving.

Table 1. *Base case values for variables included in the model evaluating the PSS.*

Variable	Symbol	Unit	Value
The total cost of the PSS	IS	Euro	0.3
The total cost of the AFS	IC	Euro	505.2
Discount rate	R	%	275.5
Additional annual returns	AR	Euro	20
Fuel price	H	Euro/L	1562.6
Fuel consumption in greenhouse C	F_C	1	0.2
Fuel consumption in greenhouse S	F_S	1	1112
Annual fuel expenses saved	SF	Euro	240
Harvest cost	K	Euro/kg	164.4
Quantity harvested from greenhouse S	Q_S	Kg	0.0
Quantity harvested from greenhouse C	Q_C	Kg	20900
Additional annual harvest costs	AE	Euro	18078
Maintenance cost of the PSS	MN	Euro	40.9

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***Table 2.** Financial analysis of the PSS (0.l ha tomato greenhouse)*

Year	C.O.F	D.F (20%)	D.C.O.F	C.I.F	D.C.I.F	D.C.F
1	633.10	0.83	527.37	2002.48	1668.07	1140.69
2	127.92	0.69	88.77	1726.98	1198.52	1109.75
3	633.10	0.58	366.56	1726.98	999.92	633.36
4	127.92	0.48	61.66	1726.98	832.40	770.75
5	633.10	0.40	254.50	2002.48	805.00	550.49
6	127.92	0.34	42.85	1726.98	578.54	535.69
7	633.10	0.28	176.63	1726.98	481.83	305.19
8	127.92	0.23	29.81	1726.98	402.39	372.58
Total	**3044.07**	**3.84**	**1548.16**	**14366.83**	**6966.66**	**5418.50**

NPV at 20% = 6966.66 - 1548.16 = 5418.50. Benefit/cost ratio at 20% = 4.5
C.O.F = cash outflows; D.F = discount factor; D.C.O.F = discounted cash outflows; C.I.F = cash inflows; D.C.I.F = discounted cash inflows; D.C.F = discounted cash flows

IRR

The IRR was not taken into consideration because all the terms of the discounted cash flows are positive (*Table 2*). In this case, the NPV is positive at each value of interest rate, so that the NPV does not cross the interest rate axis and the determination of the IRR is impossible.

Benefit/cost ratio

The evaluation of a project by the benefit/cost ratio method requires acceptance of the project if the ratio is greater than one. The ratio here was 4.5, confirming the NPV method and indicating the profitability of the PSS when it replaces an AFS.

Evaluation of the PSS by variety (Arietta)

The evaluation of the PSS for each tomato variety is similar to that above, which did not distinguish between varieties; the only change concerns the additional annual returns (AR) and the additional annual harvest costs (AE). Financial analysis for each variety is presented in *Table 3* and the financial analysis of Arietta variety is presented in *Table 4*. The determination of the IRR is impossible for all varieties since the terms of the discounted cash flows columns are positive so that the NPV will never be zero.

Evaluation of the DFS

Several parameters were determined before calculation, summarizing the variables included in the case of no distinction between varieties (*Table 5*). As in the case of the evaluation of the PSS, the discount rate was assumed to be 20% and an assisted computer program was used to determine the parameters (NPV, IRR, and benefit/cost ratio). *Table 6* summarizes the discounted cash flow approach.

***Table 3.** Financial analysis of the PSS for the four tomato varieties*

Parameter	Carmello	Arietta	Dombo	Ramy
NPV (Euro)	6675.86	6736.97	3359.73	4901.28
Benefit/cost ratio	5.2	5.3	3.3	4.2

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Table 4. *Financial analysis of the PSS (0.1 ha tomato var. arietta greenhouse)*

Year	C.O.F	D.F (20%)	D.C.O.F	C.I.F	D.C.I.F	D.C.F
1	640.90	0.83	533.87	2353.90	1960.80	1426.93
2	135.72	0.69	94.19	178.84	1442.41	1348.22
3	640.90	0.58	371.08	2078.40	1203.40	832.31
4	135.72	0.48	65.42	2078.40	1001.79	936.37
5	640.90	0.40	257.64	2353.90	946.27	688.63
6	135.72	0.34	45.47	2078.40	696.26	650.80
7	640.90	0.28	178.81	2078.40	579.88	401.06
8	135.72	0.23	31.62	2078.40	484.27	452.64
Total	**3106.50**	**3.84**	**1578.11**	**15278.67**	**8315.08**	**6736.97**

NPV at 20% = 8315.08 - 1578.11 = 6736.97. Benefit/cost ratio at 20% = 5.3

Table 5. *Base case values for variables included in the model evaluating the PSS*

Variable	Symbol	Unit	Value
The total cost of the DFS	IS	Euro	2914.50
The total cost of the AFS	IC	Euro	362.50
Discount rate	R	%	0.06
Additional annual returns	AR	Euro	1324.29
Fuel price	H	Euro/L	0.19
Fuel consumption in greenhouse C	F_C	1	3.22
Fuel consumption in greenhouse F	F_F	1	15.10
Annual fuel expenses saved	SF	Euro	772.10
Harvest cost	K	Euro/kg	0.01
Quantity harvested from greenhouse F	Q_F	Kg	57.75
Quantity harvested from greenhouse C	Q_C	Kg	52.43
Additional annual harvest costs	AE	Euro	26.64
Annual electricity consumption	EC	Euro	14.27

Table 6. *Financial analysis of the DFS (0.1 ha tomato greenhouse)*

Year	C.O.F	D.F (20%)	D.C.O.F	C.I.F	D.C.I.F	D.C.F
1	3727.50	0.83	3105.01	1686.79	1405.09	-1699.91
2	813.00	0.69	564.22	1324.29	919.09	354.84
3	813.00	0.58	470.73	1324.29	766.76	296.03
4	813.00	0.48	391.87	1324.29	638.31	246.44
5	813.00	0.40	326.83	1686.79	678.09	351.26
6	813.00	0.34	272.36	1324.29	443.64	171.28
7	813.00	0.28	226.83	1324.29	369.48	142.65
8	813.00	0.23	189.43	1324.29	308.56	119.13
Total	**9418.50**	**3.84**	**5547.26**	**11319.30**	**5528.98**	**-18.28**

NPV at 20% = 5528.98- 5547.26= -18.28. IRP = 19.6%. Benefit/cost ratio at 20% = 0.997. Pay-back period = 5 years

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NPV

The application of the model leads to an NPV of -18.28 euro. Thus, there is no need, in terms of profitability, to replace the AFS by the DFS despite its effectiveness in increasing production and gross returns.

IRR

Here, the conditions of Vafaeipour et al. (2014) for the existence of the IRR are satisfied; the IRR was 0.196, slightly lower than the assumed discount rate.

Benefit/cost ratio

Using the benefit/cost ratio to evaluate the DFS, a ratio of 0.997 was found. This value is less than one, so this system did not add anything when it replaces the AFS. This confirms the results for NPV and IRR, which also showed the ineffectiveness of the DFS compared with the AFS.

Pay-back period

The stream of expected proceeds was not constant from year to year. The pay-back period was determined by adding up the proceeds expected in successive years until the total was equal to the original outlay. Subtracting cash inflows from cash outflows (*Table 6*) showed that investment will be covered by the returns after 5 years, which is the pay-back period.

Evaluation of the DFS by a variety

The only changes concerned the AR and the AE. Financial analysis for each variety is presented in *Table 7* and the financial analysis of Arietta variety is presented in *Table 8* in which NPV, IRR, benefit/cost ratio and pay-back period are illustrated. Thus, it is profitable to replace the AFS by the DFS only for arietta; NPVs for the other varieties were negative, varying between -1162.29 euro (dombo) and -223.85 euro (ramy), the IRRs were lower than the assumed discount rate (20%), and the benefit/cost ratios were less than one. The implementation of the DFS was also characterized by a long pay-back period, more than 8 years for dombo.

Risk and uncertainty

Because the PSS appeared to be an efficient method for greenhouse heating, NPVs were estimated by assuming changes in certain critical factors expected to affect the results such as discount rate, fuel price, and product price. The analysis did not distinguish between varieties.

Table 7. *Financial analysis of the DFS for the four tomato varieties*

Parameter	Carmello	Arietta	Dombo	Ramy
NPV (Euro)	-473.70	1960.10	-1162.29	-223.85
IRR %	10	62.5	-5.5	15.3
Benefit/cost ratio	0.91	1.35	0.79	0.96
Pay-back period (year)	6	3	>8	5

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Table 8. *Financial analysis of the DFS (0.1 ha tomato var. arietta greenhouse)*

Year	C.O.F	D.F (20%)	D.C.O.F	C.I.F	D.C.I.F	D.C.F
1	3739.78	0.83	3115.26	2169.48	1807.17	-1308.09
2	825.31	0.69	572.77	1806.98	1254.04	681.27
3	825.31	0.58	477.86	1806.98	1046.24	568.38
4	825.31	0.48	397.80	1806.98	870.96	473.16
5	825.31	0.40	331.78	2169.48	1045.69	713.91
6	825.31	0.34	276.48	1806.98	605.34	328.86
7	825.31	0.28	230.26	1806.98	504.15	273.88
8	825.31	0.23	192.30	1806.98	421.02	228.73
Total	**9517.01**	**3.84**	**5594.51**	**15180.80**	**7554.61**	**1960.10**

NPV at 20% = 7554.61 - 5594.51 = 1960.10. IRR = 62.5%. Benefit/cost ratio at 20% = 1.35. Pay-back period = 3 years

Effect of the discount rate

To determine the effect of the discount rate on the NPV, decreases, and increases in this discount rate were examined. Thus, the NPV is related to the discount rate: when this rate decreased by 50%, the NPV increased by 39%; the NPV increased by 6% when the discount rate decreased by 10%. However, when the rate increased by 10%, the NPV decreased by 5.5% and a 50% increase in the discount rate caused a 24% decrease in the NPV. Such changes in the interest rate are more significant when the percentages are lower (*Fig. 1*).

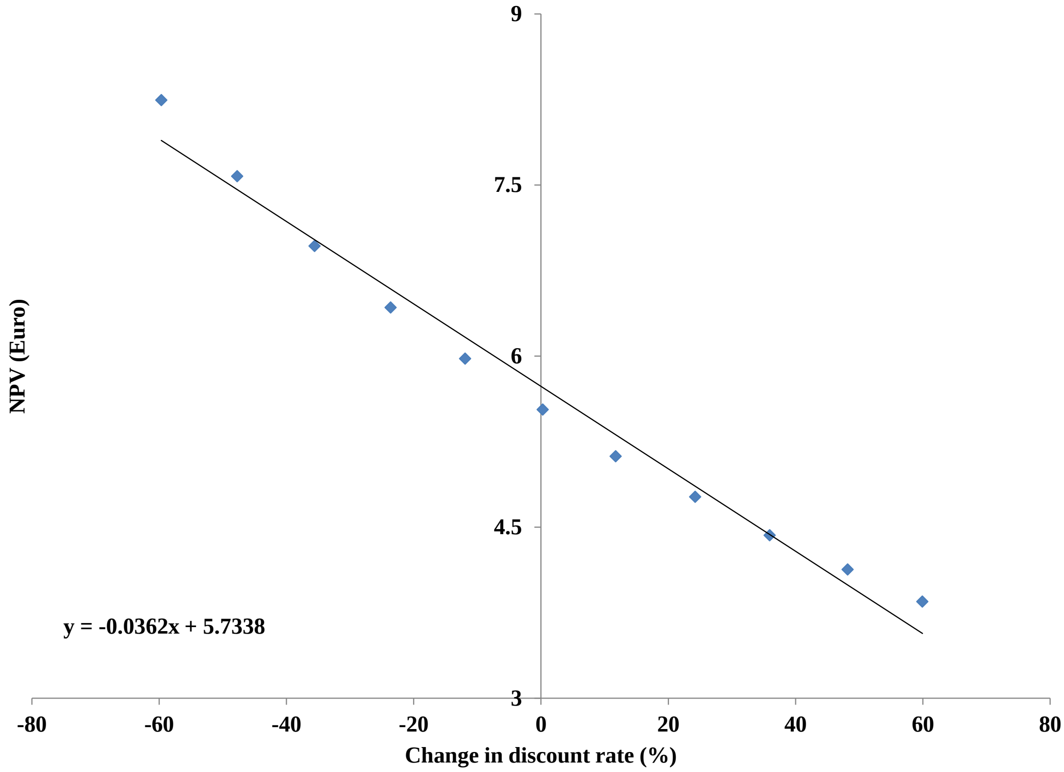

Figure 1. *The effect of a change in discount rate on the NPV for the PSS*

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Effect of the fuel price

The effect of the fuel price on farmer income with the PSS instead of the AFS is summarized in *Figure 2*. The effect of a change in the price of fuel on NPV is not important: an increase of 10% caused an increase of 1%, and a decrease of 10% caused a decrease of 1%. The relationship between fuel price and NPV is linear so that the NPV increased by 5% when the fuel price increased by 50%. The effect of fuel price on NPV is considerable when a DFS is used. In this case, an increase in fuel price affected dramatically and negatively the benefits obtained by farmers utilizing the DFS: an increase of 10% caused a decrease of more than 1500% in the NPV.

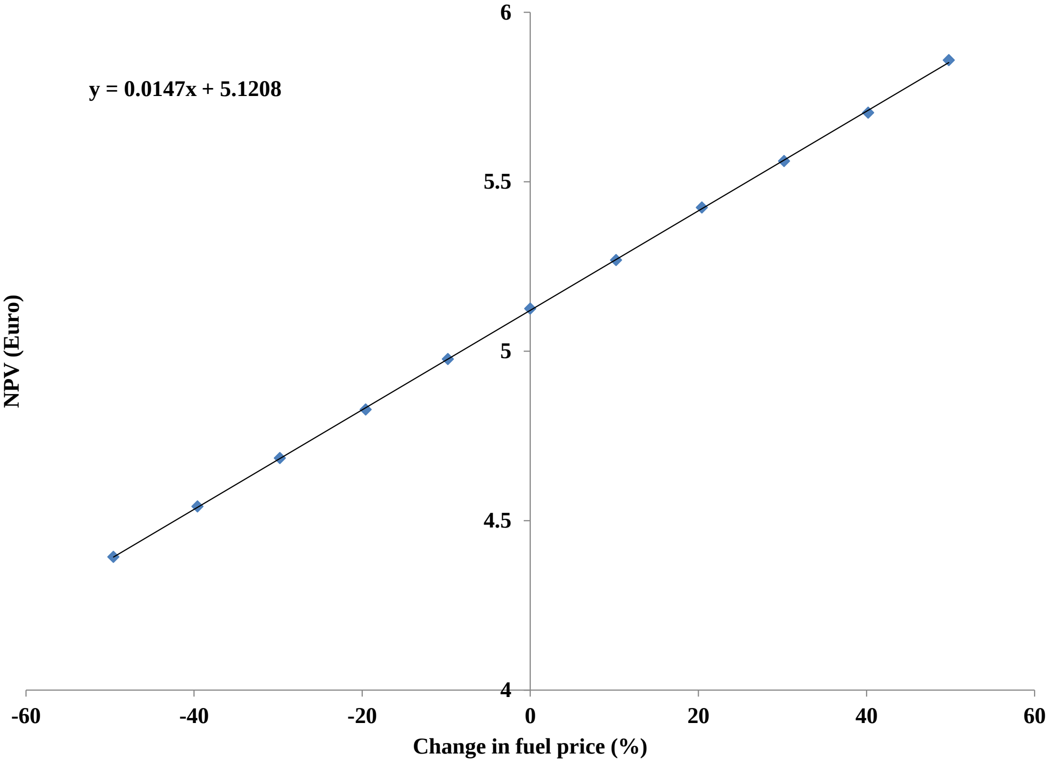

Figure 2. *The effect of a change in fuel price on the NPV for the PSS*

Effect of the product price

The product price is an important factor which affects the NPV. To demonstrate this effect, the NPV was calculated for decreases and increases in price (*Fig. 3*). Product price has a considerable effect on NPV since an increase of 10% caused an increase of 11% in the NPV. There is a linear relationship between product price and NPV, so that if the price increases by 50%, the NPV increases by 55%.

Generally, renewable energy sources require a large initial investment, but they have relatively low operating costs. The PSS significantly reduced energy consumption. The reduction in fossil fuel needs was from 80% compared with AFS to more than 2000% compared with the DFS. For an initial investment, the PSS is only 17% of the cost of the DFS, and slightly higher than the AFS. Besides its low initial investment, the PSS also has the advantage of low annual costs (13% that of the DFS and 63% that of the AFS).

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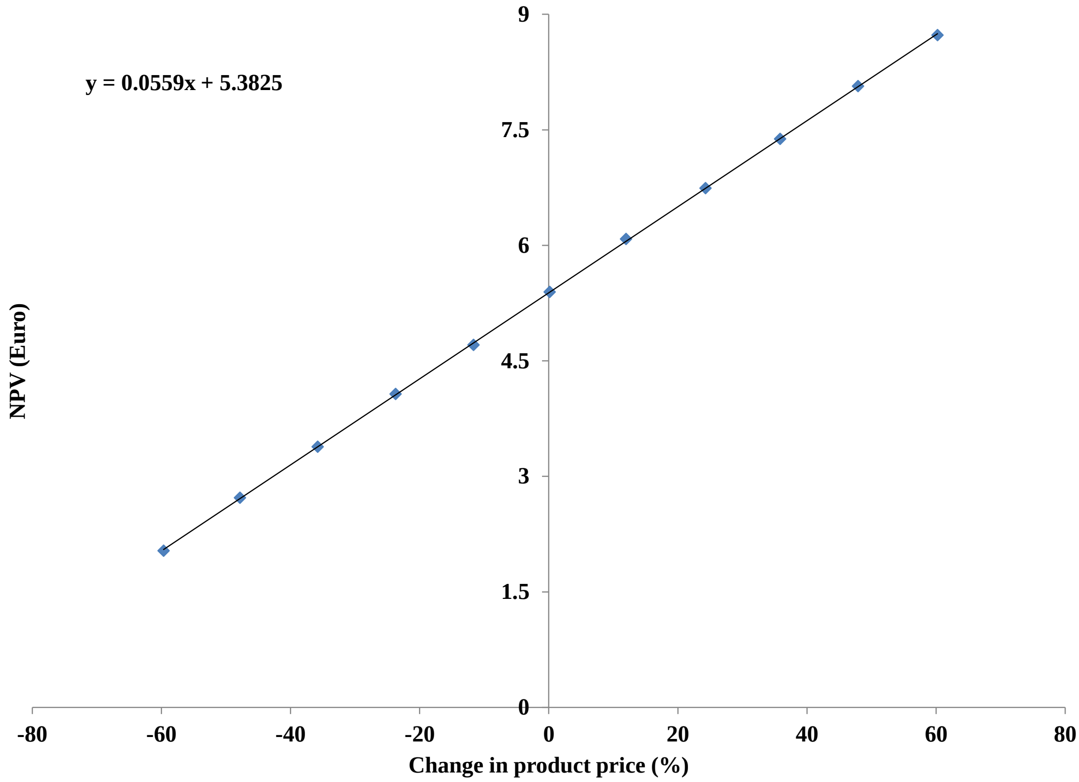

Figure 3. *The effect of a change in product price on the NPV for the PSS*

Discussion

The effect of heating systems on production and gross returns

The effect of the heating methods was that greenhouse C (AFS) had the lowest annual average production for tomato crop, greenhouse F (DFS) was 10% for tomatoes, greenhouse S (PSS) had the largest annual average production for both crops. The low production of greenhouse C was due to inefficient heating which did not maintain a uniform temperature and which may have damaged the plants (Wright, 2012).

The heating systems permitted early production which led to higher market prices. The average market price for crops grown in greenhouse C was the lowest particularly because of the competition from other field crops; since the harvest in this greenhouse started at the end of May for tomatoes (Dannehl et al., 2012).

Furthermore, gross return of tomatoes in greenhouse S was 23% greater than that in C, in agreement with Esen and Yuksel (2013), who stated that gross return of tomatoes in greenhouse with the PSS exceeds that in the control by an average of 22%, gross return in greenhouse F exceeded that of C by 19%. However, in term of production, those percentages were only 16% and 10% respectively. Gross return of melons in greenhouse F was 50% greater than that of C, with 44% more production; greenhouse S was 66% and 60% more in gross return and production, respectively. These results show how early production allows farmers to exploit the higher market prices; the earlier the production, the higher the market price achieved, this accords with Gandhi and Zhou (2014), who stated that early production permits to increase dramatically gross return.

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Evaluation of the considered heating systems

The analyses of production and gross returns show that the PSS and the DFS should be accepted over the AFS for greenhouse heating. This acceptance should be affirmed by a financial analysis which permits the adoption or the rejection of technological innovation, which is determined not by its contribution to the increase of production or to the increase of output value, but by the magnitude of the net benefits that can be provided (Cerón-Palma et al., 2012). It was clearly seen that it is on the profit of the farmers to replace the AFS by the PSS, since the NPV is positive and equal to 5500 euro in the case of tomatoes over an 8-year period (2012-2014), with 2012 as the base year.

Presented results indeed manifest PSS's importance as a significant contributor to farmer's income, thus a farmer with a 0.1 ha greenhouse cultivated with early spring tomatoes, will add annually about 750 euro just by utilizing the PSS and the greater the area cultivated, the greater the income added, thus a farmer who has five 0.1 ha tomato greenhouse will add approximately 3650 euro/year to his net benefits just by introducing this renewable energy-saving method (Jamel et al., 2013; Nabat et al., 2015).

As well as the NPV method, the benefit/cost ratio which was greater than 1 for the tomato crop indicates the importance of this system, the pay-back period is so short (less than one year) avoiding the problem of risk and confirming the decision provided by the previous discounted techniques (NPV and benefit/cost ratio) this is especially due to the low initial investment and fuel consumption characterizing PSS. The IRR method was not taken into consideration because this investment project does not meet the conditions imposed by Vafaeipour et al. (2014).

Besides its effectiveness in term of income and net benefits, the PSS presented the advantage of an energy-saving method which is very important particularly for a country like Greece, which is characterized by its heavy dependence (more than 70%) on primary energy from imported oil (Mourmouris and Potolias, 2013) and (Markaki et al., 2013), thus the reduction in fuel consumption was more than 20 times when compared with the DFS in the case of tomatoes.

On the other hand, the implementation of a DFS for heating tomato greenhouses against an AFS is not profitable: NPV was negative, IRR was lower than the assumed discount rate, benefit/cost ratio was less than one and pay-back period of 5 years is relatively long compared to the project life, at a much higher risk characterizing this system (Mehrpooya et al., 2015). The exception of arietta variety which had a positive NPV and an IRR greater than 20% and a relatively short payback period is especially due to its considerable difference in term of production between greenhouses F and C, which permitted to produce higher additional annual returns (AR) (Mekhilef et al., 2013).

It is important to note that despite its effectiveness in term of production and gross returns, the DFS did not provide any benefits for farmers when it replaces the AFS, this is particularly due to its relatively high initial investment and its large fuel consumption (Sueyoshi and Goto, 2015).

Sensitivity analysis

Sensitivity analyses were performed by varying certain critical factors such as discount rate, fuel price and product price over the range established, keeping the other

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variables at base case levels, this showed how the value of the NPV changes with variations in the value of any variable. Product price was the most important factor affecting the NPV: a price increase of 10% caused an increase of 11% in the NPV for tomatoes, and there was a linear relationship between product price and NPV, in an agreement with Vafaeipour et al. (2014), who stated that product price appears to cause the greatest effect on estimated income benefits. Thus farmers should choose the most appropriate heating system to have early production and therefore higher prices and benefits (Orgerie et al., 2014).

However, an increase in fuel price decreases income significantly when a DFS is used against an AFS; an increase of 10% caused a decrease of more than 1500% in the NPV of tomatoes, increasing risk associated with the implementation of the DFS because fuel prices generally increase with time, especially for oil-importing countries such as Greece (Markaki et al., 2013).

The NPV is also related to the discount rate: an increase of 10% caused a decrease of 6% in the NPV's of tomatoes. It is also important to note that a change in the discount rate is more significant in the case of negative change: for example, when R increased by 50% (R = 30%) NPV decreases by 24%, but a decrease of 50% (R = 10%) caused an increase of 39% in the NPV, giving an advantage to farmers from countries with low-interest rates (Vadiee and Martin, 2014).

Risk and uncertainty associated with renewable energy

In contrast to the use of fossil fuel energy sources, renewable energy sources generally require a large initial investment because of the large initial costs. This is especially important in countries which have high-interest rates (Mohammed et al., 2014). The relatively large initial investment required means that such projects will have relatively long pay-back periods and therefore, they involve much higher risk than that associated with fossil fuels (Castilla, 2013).

Renewable energy projects also face uncertainty regarding possible changes in economic conditions between the time the initial investment takes place and the length of the project's useful life. Of course, there is a wide range of risk associated with different renewable energy sources. Economic uncertainty is mainly due to possible changes in future energy prices. For example, few who anticipated the decrease in crude oil prices in 1985 and 1986, and many analysts were surprised to discover that 1986 real oil prices were at the pre-1973 level (Xu et al., 2014).

PSS differs from other renewable energy systems in that it has a low initial investment (17% of that of conventional DFS), thus indicating its advantage in avoiding the risk of high initial investment which is generally associated with renewable energy (Mourmouris and Potolias, 2013). In term of operating costs, the PSS has the advantage of renewable energy sources, which are characterized by the low operating annual costs. Thus by the low initial investment and the low annual costs, it may be useful to encourage the use of the PSS for greenhouse heating (Foteinis and Tsoutsos, 2017).

Conclusions

The evaluation of the current system in comparison with the most common non-renewable greenhouse heating system revealed its importance not only as an energy-saving technology, with considerable reductions in fossil fuel consumption, but also as a significant contributor to farm income. The implementation of the passive solar system

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instead of the traditional anti-frost one has dramatically increased production and gross returns particularly through its promotion of early production. The financial analysis which is based on different methods used as a basis on which to assess the investment profitability of a project (NPV, IRR, benefit/cost ratio and pay-back period) demonstrated that the adoption of the passive solar system significantly increases the earnings of greenhouse farmers. This study also revealed the advantage of this system in avoiding the risk of high initial investment which generally associated with renewable energy systems, and sensitivity analysis indicated the importance of product price in affecting benefits, thus early production allows farmers to exploit the higher market prices. This system is appropriate for any region whose climatic conditions are sufficiently similar to those of northern Greece. Financial analysis also revealed that investment in a diesel-fired furnace system did not provide any considerable benefits when it replaces an anti-frost system; its inefficiency is particularly due to its relatively high initial investment and its large fuel consumption.

For further consideration where the costs are not the only issue, the major obstacle to the wide application of renewable energy sources is higher risk and, uncertainty and not simply the cost of the energy utilized. Therefore, the main role of the public in such projects should be directed toward sharing some of the risk involved in construction and the operation.

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