Plant design and economics of Rice Husk Ash exploitation as a pozzolanic material

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Abstract
Biomass produced ashes, upon certain conditions (chemical configuration, level of fineness) can posses pozzolanic properties. Rice Husk Ash (*RHA*), an agro-industrial by-product produced of the rice industry, can be utilized successfully (in terms of concrete properties and durability indicators) as a pozzolanic material (replacing cement to a certain extend) in concrete mix design. The question is if such an endeavor is viable from an economic point of view. Such is the aim of this study. Upon a brief presentation of some of the authors' research results on the sound viability of RHA as a cement replacement material, an assessment of the techno-economical characteristics of RHA production is taking place. Particular attention has being paid to factors as treatment process, fixed/operational cost, production cost and profit. In addition cost-benefit and sensitivity and risk analyses were also performed aiming to evaluate the economic viability for investment on RHA pozzolanic material production and the dependence of investment characteristics on production capacity. Overall, the techno-economical analysis presented in this study provides precise demands on capital for a fixed investment, provisions for operational capital and finally provisions for revenue.

Keywords: Rice husk ash, pozzolanic material, plant design, techno economical study

1. Introduction

Given the known environmental issues associated with cement manufacturing (in terms of energy and raw materials required for its production), direct reduction of cements' clinker content via utilization of industrial by-products as supplementary cementitious materials (*SCM*), is a very promising first step in reducing considerably the associated environmental burden. On that aspect, recent research results [1-2] are indicating the feasibility of using pozzolans (as *SCMs*) originating from the agricultural industry, through biomass utilization. Various types of biomass, from agro-industrial processes, produces ash (as rice husk ash, palm oil fuel ash, sugar cane bagasse ash, etc.) which under certain conditions (chemical configuration, level of fineness) can have a similar pozzolanic activity to coal fly ash [1-3]. These agro-waste ashes, containing a large amount of silica in amorphous form, have potential for use as pozzolanic materials replacing cement [4]. In general, besides the effect they entail on early concrete strength and volume stability [4-5], they improve to a great extend the overall environmental contribution [5]. It has been calculated that 18 % replacement of Portland cement results in a 17 % reduction of the CO_2 emissions [6]. It is believed that if just 30% of cement sed globally was replaced with supplementary cementing materials (*SCM*), the rise in CO_2 emissions from cement production could be reversed [6].

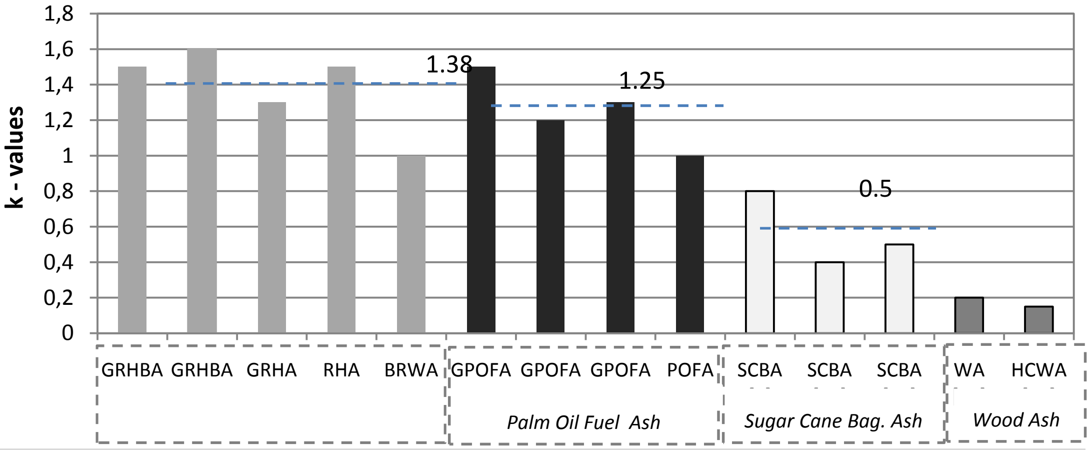
Biomass, considered as one of the major renewable energy sources (in absolute terms), accounts for more than 4% of the total energy consumption in the European Union (EU) [7]. Despite its wide use as energy source much of the waste produced remain unprocessed [8]. Most of the biomass ash produced in thermal power plants is either disposed of in landfill, or recycled on agricultural fields or forest [6]. Considering the increasing disposal cost of biomass ashes and volumes (on a worldwide scale), as well as, the fact that exploitation by the cement/concrete industry of such agro-industrial ashes can be an attractive activity for countries which use great volumes of rice husk (or other types as palm oil fuels, sugar cane bagasse) as biomass in processes of energy cogeneration, a valid, coherent, profitable and sustainable ash management/utilization scheme has to be established.

Such is the aim of the current study. In more detail; i) to illustrate the benefits of rice husk ash utilization in cement and concrete properties and ii) to look into the economics of the production of innovative Rice Husk Ash derivatives (the main focus of this study), taking into account technical and market dimensions. A Techno-Economical Study is briefly presented elucidating the economical profile of Rice Husk Ash derivatives' industrial production. The overall assessment behind such an analysis was based on factors as quantity and characterization of raw materials, proposed treatment process, fixed cost, required personnel, operational cost and product cost. The principles and results of cost-benefit and sensitivity/risk analysis performed are presented in order to obtain a more vivid picture on, the necessary level of investment associated with production of pozzolans from rice-husk ash, on the dependency of such an investment on unit capacity and on the return on investment.

2. Utilisation of Rice Husk Ash in cement and concrete

Rice husk ash (*RHA*), an agricultural waste material, produced by controlled burning of rice husk have shown to contain reactive silica and alumina (in the form of metakaolin) which could contribute chemically to the Portland cement ingredients. In general, the reactivity of RHA is attributed to its high content of non-crystalline silica, and to its very large surface area governed by the cellular structure of the particles [9-11]. When pozzolanic materials are added to cement, the silica (SiO_2) present in these materials reacts with free lime released during the hydration of cement to form additional calcium silicate hydrates (new hydration products) [12]. Depending on the nature of husks and burning/cooling conditions, the total silica of RHA can exceed 90%, with most of it being non-crystalline, thus reactive under alkaline conditions [13].

Considerable amount of work on developing analytical models for the evaluation of *SCM* in concrete using the concept of efficiency factors (or k-values, to compare the relative performance of supplementary cementing materials on concrete durability) by Papadakis et al. [14-16] and preliminary work undertaken by Papadakis et al. [2, 13] and Demis et al. [17-18] on *RHA* has identified the high-added value of this materials on cement and mortar. By evaluating a range of highly reactive *RHAs* (with SiO_2 content of more than 90%) and other types of ashes, in terms of efficiency factors (Figure 1), it was shown that biomass ashes from a variety of agro-industrial by products can be used as cement replacement materials with beneficial results in strength development. On average a relatively high *k*-value of 1.38 was calculated for rice husk (and mixtures) ashes, indicating that the high levels of amorphous silica and the fine particle size of *RHA* are the principle reasons for the excellent pozzolanic activity and the increase in compressive strength observed.



d_{50} (µm):	10.8	10.8	12.0	3.80	15.5	10.1	19.1	10.1	10.7	5.40	-	2.70	-	5.16
SiO_2 (%):	87.0	74.8	91.0	87.3	78.4	65.3	65.3	65.3	55.5	64.2	78.4	78.3	31.8	28.0
Al (%):	1.08	0.20	0.35	0.22	2.60	2.50	2.50	2.60	9.20	9.05	8.55	8.90	28.0	4.10
Si+Al (%):	88.1	75.0	91.4	87.6	81.0	67.8	67.8	67.9	64.7	73.2	86.9	87.2	59.8	32.1
Si+Al+Fe:	90.7	75.8	91.8	87.8	82.7	69.7	69.7	69.9	70.3	78.7	90.5	90.8	62.1	34.6

Figure 1. *k*-values of biomass ashes [17]

Furthermore, evaluation of the performance of biomass ashes in terms of chloride ion penetration, (measured according to ASTM C 1202 [19]) showed that the total charge passed on biomass ash concrete samples, was considerably reduced (compared to control samples), up to almost 90% (Table 1) for a 20% replacement by RHA. Overall, the chloride-ion penetration results suggest pore refinement due to the pozzolanic reaction of ultrafine biomass ash and demonstrate the significant potential of these types of ashes as mineral admixtures in concrete, as long as an appropriate grinding strategy is used and product fineness is achieved.

Table 1. Performance of *RHA* concrete mix in RCPT in terms of reduction in electrical charge passed [17]

SCM (%)	RHA [25]		RHA [31]		RHA [26]	
	(C)	**D(%)**	*(C)*	**D(%)**	*(C)*	**D(%)**
0	*1161*	0	*7450*	0	*2870*	0
5	*1108*	4.57	-	-	*2200*	23.3
10	*653*	43.8	-	-	*1500*	47.7
15	*309*	73.4	-	-	*1250*	56.5
20	*265*	77.2	*750*	89.9	*1000*	65.2
25	*213*	81.7	-	-	*850*	70.4
30	*273*	76.5	-	-	*780*	72.8
35	-	-	-	-	*950*	66.9
40	-	-	*250*	96.6	-	-

(C) Charge passed (in Coulombs), (D) Difference to the control value (%)
charge ranging from 1000 to 2000 C: low permeability, from 100 to 1000 C: very low permeability

The overall contribution of *RHA* as *SCM* in concrete mix design has been presented at another publication [20], in which an evaluation in terms of durability, concrete compressive strength and environmental cost indicators took place (for a range of other types of *SCMs*, as well). As durability indicators, calculation of the carbon dioxide penetration front, for a period of 50 years, was used for carbonation exposure, while under chloride ingress, the estimation of the adequate concrete cover needed to sustain a service life of 50 years was calculated. The environmental footprint of each individual concrete component was estimated, based on data from the literature and from production and operational data from cement-manufacturing companies. Results (Figure 2) indicate that the use of *RHA* as an addition to a concrete mix, replacing either aggregates or cement, significantly decreases the adequate concrete cover needed to sustain chloride exposure for a service life of 50 years, hence prolongs the service life, while at the same time considerable reductions of the total concrete CO_2 emissions were noticed.

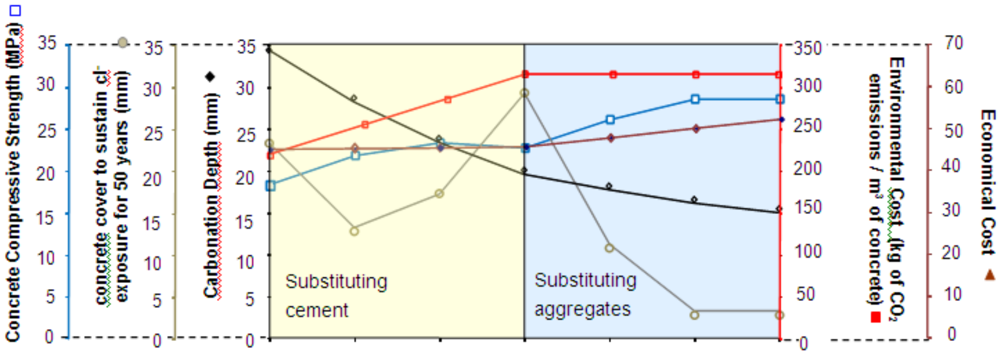


Figure 2. Durability and cost indicators for RHA concrete mixes [20]

Bearing all of the above in mind, the beneficial effects of the utilization of *RHA* as a pozzolanic material becomes quickly apparent. It was also shown that it is possible to achieve an adequate level of "green" durability in concrete design, in other words a balance between sustainability and durability, by utilising RHA in the concrete mix. But to what economic extent? What are the relative financial indicators for utilization of *RHA* derivatives in concrete production? Questions, that the following section will try to answer.

3. Techno-economic analysis of RHA production

On the development of a pozzolanic material from RHA, the most critical process is the conversion of the raw *RHA* (**RR**) to upgraded *RHA* (**UR**) that meets the customer requirements, i.e., fineness level (Equation 1), which takes place in the mill. Production of an improper RHA (**IR**), RHA that does not fulfill the requirements set, or its treatment is non-economically viable has been also included.

Raw RHA (*RR*) → Upgraded RHA (*UR*) + Improper RHA (*IR*) (Eq. 1)

The production process involves three main stages, the i) homogenization of the raw material (RR), ii) the milling of RR to final product (UR) and iii) the homogenization of the final product and storage for disposal (Figure 3). Overall, production must contribute to the effort of homogenizing rice husk ash (that will be burned), before its supply to the grinder in order to avoid significant fluctuations in *RHA's* composition and to ensure better energy exploitation of fuel. Continuous sampling of the raw material should take place before its supply to the silos. The samples should be checked for sulphates (SO_3) and levels of free CaO, and be able to form an opinion about the exact quality of the ash that will go through grinding. Samples that do not meet the levels set (e.g., 3% for sulphate or 2.5% for free CaO) should be discarded. The treated ash should be stored in different silos in layers, so that the final product that will result from each silo be as homogeneous as possible. Usually in order to ensure product homogeneity, a series of six (6) silos for storing raw material and three (3) silos for storing the final product are utilised. Hence, the raw material for processing will result from all six silos and the final product for distribution will result from all the three silos containing the final product.

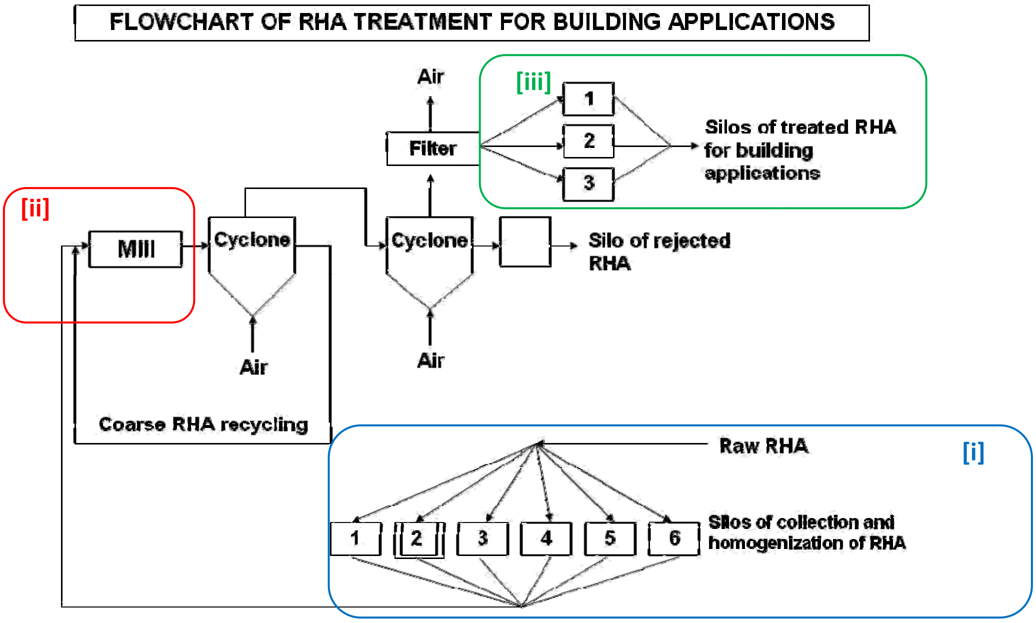


Figure 3. Process for pozzolanic material production from RHA.

Based on data of *RHA* production in Greece [21], an initial capacity of 1000 t UR /y is considered as the basic scenario. As the production rate is estimated at about 1000 t/yr, with a solid-treatment character *the batch operation* is selected instead the continuous one, meaning that the specific plant for RHA treatment will operate only for one (1) eight-hour shifts per day (*5 days per week, 47 weeks per* year (5 weeks closing of factory for maintenance). Total production days: 235 per year). In terms of product specifications, according to customer requirements or to the European Standard EN-450 for use of fly ashes into concrete, the related parameters are, homogeneity, fineness level (retained in 45μm sieve < 40% by weight), levels of free CaO and sulphates SO_3 (less that 1-2.5%, 3% respectively) and loss of ignition less than 5%.

3.1 Calculation of initial working capital, fixed and operational cost

Establishment of any industrial plant requires expenditures for a number of tasks studies' elaboration, purchase of land/configuration, purchase/ installation of equipment, interfaces, components, etc. The total cost required from the conceptual design (stage of capturing the idea) to the development of the production unit (just before the start of its normal operation), is the Establishment Capital, *EC* (Equation 2). It consists of the fixed capital (*C*, costs for the acquisition or construction of equipment and installation) and the initial working capital (*IC*), cost required in order production to achieve a level of normal operation.

$$\text{Establishment Capital } (EC) = \text{Fixed Capital } (C) + \text{Initial Working Capital } (IC) \qquad \text{(Eq. 2)}$$

The *initial working capital* covers operating expenses from the start of production until the generation of revenue from product sales (we assume a six month period). It covers cost of raw and auxiliary materials, wages/ salaries, cost of product delivery as well as for test operation. Since it is not possible (at least not until the design has proceeded satisfactory) to calculate all of the above factors, the *IC*, can be estimated as a percentage (5% - 30%) of fixed capital, C (usually 18%, hence in our study *IC equals to* 55.540 €). In this way the Establishment capital (total fixed cost + initial working capital, 364,000 € in this case) can be calculated. In the case were establishment or fixed cost has to be estimated for another production rate (capacity), Equation **3** can be used.

$$C_2 = C_1(Q_2/Q_1)^n \qquad \text{(Eq. 3)}$$

where, Q_1, Q_2 : capacities (t/y), $C_{1,2}$: fixed (or establishment) capital for capacity Q_1, Q_2 respectively and n a statistical parameter. The exponent n varies depending on the kind of the investment, (for chemical industries n equals usually to 2/3; that is the reason for calling this method as "method of 2/3"). Every individual component of the fixed cost, *C*, calculated in this study, is shown in Table 2. Values (in euro, €) are the result of market research in 2012.

Table 2. Components of fixed capital (fixed cost)

Installations and machinery (10 years)	
Electromechanical equipment / mill / depreciation	75,000
Installations / piping / 13% of basic equipment	10,000
Equipment for quality control laboratory	28,000
15 homogenization silos / storage, (50 t each)	82,500
Packing-loading unit	28,000
1 loading machine - Clark	10,000
Subtotal	233,500
Buildings and land	
Offices / laboratory / storage & buildings for equipment	47,000
Fencing	-
Land property (own property)	-
Subtotal *(depreciation in 25 years for everything - out of land property*)	47,000
Total	280,500
10% unpredictably	28,050
Total fixed cost	**308,550**

As it was previously mentioned, the *initial working capital* refers to costs that are required in order for the production to achieve a level of normal operation. Usually, from this point on, *only operating costs* and *revenues* from the sale of products exist. Revenues from sales, *R* (€/y), in general, can be assessed via market research, which will determine both the price and quality of products that the customer wants. For the purpose of basic calculations, the price can be determined from the literature and from similar undertakings abroad or from direct information from the potential customers and market. For the present study potential Revenues, *R* are assumed to be 420 €/t, hence 420,000 €/y for a production capacity of 1000 t/y.

Every individual element comprising the operational cost, *OC* (€/y) and their calculation via a set of cost factors is shown in Table 3. It should be noted that these factors vary in the literature, thus they might lead to a considerable level of uncertainty in the calculations. In this study, to account for such discrepancy average values from literature, modified according to cases which applied in Greece, have been used.

Table 3. Elements of Operational Cost (in €/y)

Description	**Calculation Methodology**	**Value (in €/y)**
Raw and auxiliary materials	*Calculation from mass balance*	70,000
Energy	*Calculation from energy balance*	26,700
Labour costs	*Calculation*	78,400
Maintenance	*0.05 C*	11,670
Administrative expenses	*0.50 of Manpower*	106,400
Insurance fees	*0.01 C*	2,330
Depreciation	*0.10 C*	25,230
Interests	*Calculation*	-
General costs	*0.03 R*	12,600
Taxes	*Calculation*	
	Total Operational cost (no taxes), OC′	**333,340**

* C : fixed cost, R : revenues

Calculation of *raw and auxiliary materials* is achieved with the use of balances and cost of materials. RHA has a potential for selling at a lowest price of 70 €/t, thus it has to be charged to the operational costs as price for raw material (hence, Untreated RHA, AR : 70 €/t, for a 1000 t/y production rate, yields an operational cost of 70,000 €/y).

Overall, in order to calculate the operational cost it is essential to determine (at least) the energy balance. In terms of energy cost required, the mill power and the power balance depend heavily on the operational capacity of the plant (production rate). By assuming industrial use of medium voltage power (B1B and B2B) from the Public Power Corporation (DEI), the *energy cost* is defined according to Equation 4.

Mill power (234 kWh/t · 0.1€/kWh · 1000 t/y): 23,400 €/y
Power balance (33 kWh/t · 0.1€/kWh · 1000 t/y) : 3,300 €/y (Eq. 4)
Total: 26,700 €/y

Labor costs, refers to staff working exclusively at the production. Calculation of such manpower is relatively easy and requires little experience. The number and the salaries of workers depend on the particular characteristics of the country (e.g., institutional framework, productivity). In this case, these are calculated based on average values, also containing insurance (namely, 4 technicians/workers · 1,400 (average) €/month · 14 months: 78,400 €/y). *Maintenance* includes all expenses for regular maintenance, and repairing of damages. The cost of maintenance is assumed to be equal to 5% of fixed capital. *Administrative costs* include expenses incurred for the support of production (administrative staff, offices, sales network, etc.) and are typically considered to be equal to 50-60% of the labor cost. In the current study they were calculated based on an established structure (1 director · 2,000 €/month · 14 months, 1 chemist/R&D consultant · 1,400 €/month · 14 months, 3 administrative staff · 1,400 (average) €/month · 14 months and Compensation for President and BoD members · - €/m x14 months). *Insurance* fees refer to the plant site and the products. Is it possible to assess its value from market information, but also it may accurately be calculated as 1% of fixed capital.

Depreciation expresses in an accounting manner, the return of the fixed capital. There are different methods of calculation, with the linear depreciation being the simplest and most widely used. The depreciation periods vary for the different assets, and are regulated in a legislative way. With the (realistic) assumption that the lifetime of a chemical industry is 10 years and with the use of the straight-line method, a 10% annual depreciation of the fixed capital is calculated. Here, we have defined the depreciation years during the calculation of fixed capital and we consider linear depreciation with zero residual value (hence Depreciation = 0.10 · 233,500 + 0.04 · 47,000).

The term *Interest* refers to the interest of the initial working capital and to the interest of loans for the purchase of equipment. *General costs* refer to costs for research and development (R&D), sales promotion and royalty payments for use of technology or product label. They vary considerably depending on the product and the business policy. Approximately, the general costs may be considered to represent 3% of revenues. In terms of *taxes*, the tax rate is regulated legislatively in each country. In Greece, the tax rate is approximately 30-40% (although there are slight differences depending on the type of business). Tax is calculated on the amount obtained when deducting the operational costs excluding taxes from the income (T = 0.30 (R – OC′), where, R: revenues, OC′: operational cost excluding taxes).

3.2 Market Competition and Sales

The emerging market opportunity for *RHA* investigated in this study is to be used as a pozzolanic material in concrete. Since silica fume, which is a very good material with exceptional properties, is already available on the market, the aim is to make *RHA* similar to silica fume or to replace silica fume by RHA. RHA is currently not being used to any extent, except in the USA, however, it is estimated that there is great potential for its use in the cement markets. The limited use of RHA is attributed to lack of awareness of the potential for this material and the quality of the product itself.

The cement industry has to produce a consistent, high quality and standard product. This in turn requires RHA from a controlled combustion environment, to ensure a consistent standard ash. Ash of a consistent quality is not readily available and is therefore not used by the cement industry. There are many other cheaper and more abundant pozzolans available. A waste product from coal fired power stations is pulverised fly ash (PFA). It is abundant and cheap and is therefore often used as an admixture in high strength concrete. Ground granulated blast furnace slag produced from iron smelters is also highly pozzolanic and available. However, for high strength and quality, silica fume is preferred, for which RHA is a potential substitute in various applications such as specific types of concrete, shotcrete, self-compacted concrete, high-strength, high performance concrete, repair mortars, etc. Thus, a focused market research on silica fume is necessary.

According to real market and contacts with potential customers the price range for pozzolanic materials derived from *RHA* is 300-420 €/t, depending on quality (fineness, color).The market price for silica fume in Greece is 500 €/t since there is not any production of the material but only importation. Thus, a *feasible, good price* to use as a scenario basis in the present technoeconomical analysis is 420 €/t for *RHA as pozzolanic material* for building applications.

4 Cost-benefit analysis and evaluation

The investment decision is a critical process since it depends on certain factors that need to be addressed as plant capacity and implementation time. Capacity is strongly related to demand. If capacity is greater than demand, fixed cost increases and the need to operate at lower capacity become obvious. When capacity is less than demand similar problems might arise. The timing of the investment is also very crucial and there are cases that it affects its viability. For instance, if there is increased demand for a product, then the proper conditions for implementing the relevant project are set. However, if investment fails to be implemented on time then it is possible that the corresponding demand will be satisfied through the availability of another product or the consumer preferences might change.

Despite the uncertainty that accompanies an investment decision, it is possible to measure the economic efficiency based on the assumptions that have been made (capacity, product's price, etc.). The criteria or methods that are presented below give the opportunity to an investor or sponsor to determine the efficiency of the under evaluation project and compare it with other standards or alternative investments. From the existing methods of economic evaluation of investments, the most common will be used: the method of *return on investment rate* and *payback period (or payout method)*. The return on investment can be defined according to Equation 5.

$$i_r = K / (C + IC) \qquad \text{(Eq. 5)}$$

where, K: the annual net profit (revenues - total operational costs), C: total fixed cost of investment, and IC: the initial working capital. Obviously among two or more alternative investment plans, the one with the greater i_r will be selected. When considering a single investment plan then i_r should be greater than a minimum acceptable rate of return which is set by the company. This method ignores the value change of money as a function of time.

With the payout method, the time needed to recover the establishment capital is determined from the generated revenues during the operation of the facility. Quite simply, the payout period, τ, can be evaluated according to Equation 6.

$$\tau = (C + IC) / K \qquad \text{(Eq. 6)}$$

Among two or more alternative investment plans, the one with the shorter τ will be selected.

Based on the analysis previously presented, the expected profit, the return on investment and the payout period regarding the production of 1000 tonnes per year of pozzolanic material (almost 100% conversion of RHA to pozzolan) are shown in Table 4.

Table 4. Economical outcome of the investment for pozzolanic material production

Economical parameter	**Results for a capacity 1000 t/y**
Total fixed cost, C (€)	308,550
Initial working capital, IC (€)	55,540
Operational cost (no tax), OC′ (€/y)	333,340
Revenues, R (€/y)	420 €/t · 1000 t/y = 420,000 €/y
Taxes, [T = 0.3(R – OC′)] (€/y)	26,000
Net profit, (K = R-OC'-T) (€/y)	60,660
Return on investment, i_r (%)	**16.7**
Payout period, τ (years)	**6.0**

It can be seen that, the rate of return on investment is much higher than the current bank interest, fact which ensures that the investment is viable and it is suggested to be undertaken (if a sensitivity analysis is also positive). Furthermore, the payout period is considered as satisfactory, given that the main part of the equipment is new, and for its estimation depreciation has not been included in profit.

4.1 Sensitivity and risk analysis

Having a first positive result suggesting to undertake the investment, the positive limits should be identified and evaluated, as well as the influence of operational or market parameters on the investment outcome. An effect of capacity (production rate, t/y) analysis was performed, since it gives essential information and estimation of factors as break-even point, height of the potential losses, height of the maximum profits and efficiencies, and the targeted point of operation.

In Table 5 the investment characteristics are presented as a function of capacity. For a capacity of 500 t/y no profit – but losses are estimated. For 2000 t/y a return on investment of 36% is estimated, whereas for 4000 t/y (maximum total production in both Greek rice industry's factories) a very high return on investment 57% is estimated offering profits of 470,000 € with a payout period of less than two years.

Table 5 Dependence on capacity and on product price of the investment characteristics for the pozzolanic material production

[A] - Quantity (t/y)	*500*	*1000*	*2000*	*4000*
Economical parameter				
Total fixed cost, C (€)	213,130	308,550	460,370	707,920
Initial working capital, IC (€)	38,364	55,540	82,870	126,350
Operational cost (no tax), OC' (€/y)	215,810	333,340	562,722	1,012,460
Revenues, R (€/y)	210,000	420,000	840,000	1,680,000
Taxes, T (€/y)	0	26,000	83,180	200,260
Net profit, K (€/y)	-5,810	60,660	194,090	467,280
Return on investment, i_r (%)	**-**	**16.7**	**35.7**	**56.5**
Payout period, τ (years)	**-**	**6.0**	**2.8**	**1.8**

[B] - Price (€/t)	*330*	*360*	*420*	*500*
Economical parameter				
Total fixed cost, C (€)	308,550	308,550	308,550	308,550
Initial working capital, IC (€)	55,540	55,540	55,540	55,540
Operational cost (no tax), OC' (€/y)	330,640	331,540	333,340	335,740
Revenues, R (€/y)	330,000	360,000	420,000	500,000
Taxes, T (€/y)	0	8,540	26,000	49,280
Net profit, K (€/y)	0	19,920	60,660	114,980
Return on investment, i_r (%)	**0**	**5.5**	**16.7**	**31.6**
Payout period, τ (years)	**-**	**18.3**	**6.0**	**3.2**

T=0.3(R-OC´), K=R-OC'-T

In Figure 4 the rate of return on investment is given as a function of capacity, showing the specific curve type. One significant outcome from this figure is the estimation of the **break-even point, as Q=532 t/y**, that capacity where zero profits are estimated (i.e., revenues=expenses). **However, no operation is recommended for a capacity less than 700 t/y** as it gives return on investment lower or equal to a bank interest.

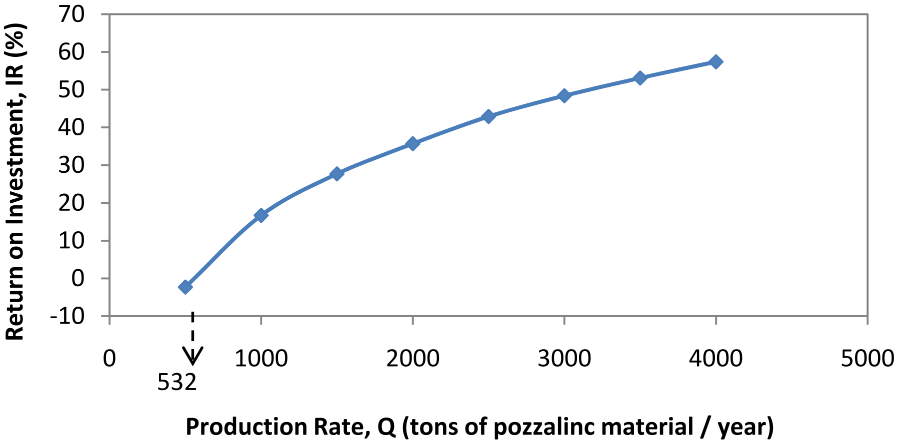


Figure 4. Return on investment vs. production rate for pozzolanic material production from RHA

Also in Table 5 the investment characteristics as a function of product price (for a stable production of 1000 t/y) are illustrated. The **break-even point** for this case is for **P=330 €/t**, a product price where zero profits are estimated (i.e., revenues=expenses). However, **no operation is recommended for a product price less than 360 €/t** as it gives return on investment lower or equal to a bank interest. For a product price of **500 €/t** (maximum price equal to silica fume value) a high return on investment 32% is estimated giving a payout period of about three years.

Finally, a comparative contribution of each operational component to the total operational cost is illustrated in Figure 6, in which a risk-free rational disribution is evident.

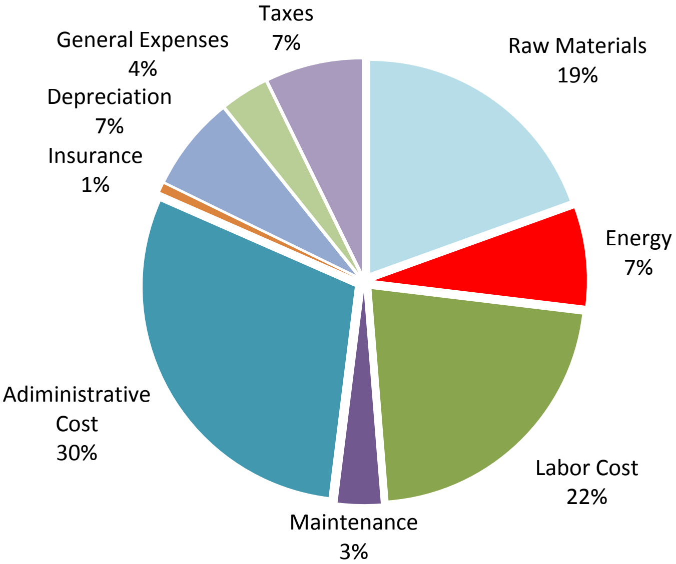


Figure 5. Comparative distribution of various operational components for pozzolanic materialproduction from RHA (Q=1000 t/y, P=420 €/t)

The most important parameters are administrative expenses, workpower, raw materials and energy, since their contribution to total operational cost is 30%, 22%, 19 % and 7% respectively. However, none of these four components could actually cause a potential risk to the investment as raw material is a property of the Greek rice company and all others cannot threat the specific investment. Thus, the distribution of the operational components seems to be rational and without hiding any particular risk.

5. Conclusions

Rice husk ash (*RHA*) can be a promising SCM with significant pozzolanic properties (high k-values) upon certain treatment. It can be successfully utilized in concrete mix design with added values in strength and service life (durability) properties. A techno-economical study for RHA production performed in this study revealed that:

- RHA conversion to pozzolanic material for building applications ensures profits and remarkable return on investment.
- The revenues of this enterprise are higher than the operational costs leaving a net profit of 60,000 euro/y for a pozzolanic material production of 1000 t/y and a positive return on investment of 17%.
- The break-even point for this production is about 530 t/y (but production rate greater than 700 t/y is recommended), whereas when the production approaches 4000 t/y a much higher return on investment of 57% is estimated (net profits of 470,000 euros).

Overall, *RHA* has proved to be a highly promising waste material providing both technical and financial benefits for immediate production on the involved industries. Hence, it is hoped that the results of this study will pave the way for a feasible and reciprocal management scheme of agro-industrial wastes, initiating in this way the successful exploitation of other biomass ashes as well.

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