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AN EVALUATION OF THE FACTORS INFLUENCE THE ELECTRIC POWER PRODUCTION FROM BIOMASS IN THE CERTAIN AREA OF KAVALA-GREECE

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ABSTRACT

This paper deals with the issue of whether then are benefits in establishing an electric power production plant (EPPP) using biomass as fuel in a certain geographical area (prefecture of Kavala/ Greece) taking into account nine certain factors that strongly influence and determine the final decision about the capacity/size and viability/feasibility of the EPPP unit proposed. Using the M. Falia Model we concluded that a certain capacity's EPPP can be established in prefecture of Kavala being viable and profitable. The nine factors used in the model are: 1. The extent of area capable to produce the biomass required for the EPPP operation; 2. The quantity of biomass required; 3. The plant mix of biomass; 4. The quality of biomass defined international standards; 5. The net thermal value 6. The ex-factory total unit cost of biomass used as «fuel»; 7. The environmental benefits quantified by us; 8. The total investment cost for the EPPP; 9. The real discount rate or International Rate of Return (IRR). The model uses the EPPP capacity as dependent variable and the nine factors as independent ones, resulted in an optimal solution about the feasibility of establishing an EPPP unit in the certain area of Kavala prefecture.

Keywords: power production, energy conversion, biomass, evaluation, factors.

1. INTRODUCTION

Biomass is essentially the solar energy stored in organic materials. Yearly, during the growth of plants, CO_2 (carbon dioxide) in the atmosphere is turned into carbohydrates through the natural photosynthesis process. These carbohydrates are organic pouches from which biomass is produced. The energy stored in the carbohydrates is released through the process of decomposition with the simultaneous release of CO_2 to the atmosphere. This process of biomass production leads to a balanced life cycle of CO_2 to the atmosphere.

The total biomass produced yearly in Greece (in the form of forest, wild plants and agricultural crops residues) is estimated to be ten million tons. In Greece, the biomass used as fuel in primary power production is only about 5% of the total energy.

To be noted, in Greece, the most important crops from which a significant amount of biomass residues is produced are wheat, rice, corn, cotton and tobacco [4]. Hence, the promotion of the energy crops to the farmers seems to be a remarkable opportunity for the development of agriculture in many rural areas. While there has been significant research in the field of biomass, mainly focused on eco-fuel production [5], little research activity has concerned the techniques of energy production [6] and the procedures of optimization of the production technology for such energy utilisation. The study of the Kavala Prefecture's biomass production capabilities s a very interesting area and it is important to investigate and evaluate whether it is profitable/viable for an electric power plant to be established using biomass as "fuel".

In this paper, based on the Fialla model [15], we will investigate whether there are benefits in establishing an electric power plant using biomass as «fuel» in pref. of Kavala taking in account nine factors that strongly influence the final optimal decision. It is a math model using multicriteria methods that leads to an optimal solution. It is very important for cases like this one to be studied because they can help the relevant state organizations to make right decisions concerning the feasibility to establish an E.P.P.P/Biomass in the certain areas.

2. The model used and some explanations

The Fialla M. *et al* [15] model defines the optimal capacity of an EPPP unit that can be designed, established, and operated in a certain area using biomass as fuel. Of course, it either maximizes the outcomes or minimizes the costs.

This model defines the electrical and thermal power of an EPPP or a number of EPPP units that can be established profitable in a given rural area. Data and information such as the quantity of biomass available in the area, technical, economic, financial, and functional factors related to the question are taken into account for this estimate [14, 15].

The model can be applied either on a country basis (i.e., Greece) or partly in smaller areas where a significant quantity of biomass can be produced by growing energy crops. To the next we will analyse the independent variables/factors influencing the choice of the optimal solution and are used in the model. Area S (km^2) is the surface where a certain quantity of biomass can cost effectively be produced from agricultural/forest residues and its availability for the production of energy. The area used as variable can be either a country (i.e., Greece) or a specific smaller area (such as a prefecture).

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Biomass density δ (tn/km^2/year) rrepresents the annual quantity of biomass produced in the specific area and comes either from the residues of agricultural or crops residues.

Below, Table-1 shows and explains the rest variables used by the Fialla model.

Table-1. Explanation of symbols.

$I_{e.}$ (EPPP'S electric power (MW)
I_{eo} EPPP's marginal electric power (MW)
I_t EPPP's thermal power (mw)
I_{eo} EPPP's optimal thermal power (mw)
K total investment cost for a EPPP unit (€)
K_o total investment cost needed for the optimal capacity of EPPP (€)
K_s investment cost /unit needed for the optimal capacity of the plant (€/mw)
K_{slim} l investment cost/unit for a EPPP with marginal capacity (€/mw)
K_{so} specific investment cost related to the optimal EPPP capacity (€/mw)
E_e electric energy produced annually (mwh/yr)
E_t thermal energy produced per year (mw/h/yr)
n_e efficiency factor of EPPP for electric power (%)
n_t efficiency factor of EPPP for thermal production (%)
TP project's annual cash flow (€/yr)
IN project's annual turnover (€/yr**)** OUT project's annual operational cost (€/yr)
IRR internal rate of return (rate %)
ΔK profitability index (%)
NPV net present value of inputs/outputs (€)
κ_b annual purchasing cost of biomass (€/yr)
κ_{bs} specific purchasing cost of biomass (€/tn)
κ_r annual maintenance cost (€/yr)
κ_t annual handling cost of biomass (€/yr)
κ_{ts} specific handling cost of biomass (€/tn x km)
irr internal rate of return (%) κ_w annual labor cost (€/yr)
f_a discount factor (%) κ_{ws} specific labor cost (€/person x yr)
f_u utilization factor of the thermal energy produced (%)
Θ_b biomass net thermalvalue (mvh/tn)
t plant annual running time(h/yr) K_r annual maintenance factor as proportion of K (%)
ΔZ_u EPPP's life cycle (yr) S_t surface of the studied area (km^2)
α_u number of employees T_t selling price of thermal energy (€/mwh)
τ_e selling price of electric energy (€/mwh) S surface of the studied area (km2)
δ average quantity of biomass yearly produced and capable to be effectively used by the EPPP unit suggested. (tns)
R_o max radial distance an area where the existed biomass can cost effectively be brought to optimal capacity EPPP located at the centre (km)

According the model Fialla, the analysis of economic benefits from investment in an EPPP is based on the IRR method [16], [17]. The most suitable economic criterion that characterises the efficient and efficiency of an investment is the profitability index (ΔK) that defines if an investment yields satisfactory profits during its operation time or not. Profitability index is related with radius R and 3 constant factors as below:

$$\Delta K = \alpha R^{-2} + \beta R + \gamma \qquad (1)$$

Where,

$$a = -\frac{f_a t \kappa_{ws} \alpha_u}{\pi \delta \Theta_b n_e K_s}$$

$$\beta = -\frac{2 f_a t \kappa_{ts}}{3 \Theta_b n_e K_s}$$

$$\gamma = -1 - f_a k_r - \frac{f_a t \kappa_{bs}}{\Theta_b n_e K_s} + \frac{f_a t \tau_e}{K_s} + \frac{f_a t n_t f_u \tau_t}{n_e K_s}$$

In Figure-1 the authors give a graphic solution where, the curve is a solution of (1) for ΔK=0. This solution corresponds to the case of a marginal capacity EPPP unit established in a certain area having radius Ro, where the capital invested covers the total costs-operational and constant- with zero profits.

The technical parameters that are valid in this case are:

a) Related to the EPPP (yearly operation cost, lifecycle period, electric effective factor and thermal effective factor).
b) Related to the biomass characteristics (net thermal value, density, unit purchase price, and collection and transport cost).
c) Related to the electric energy produced (selling price of kwh, selling price of thermal energy €/kcal).
d) Related to the economic issues, such as the IRR.
e) Related to the special plant investment cost required for a EPPP having minimum optimal capacity so that its profitability to be maximized.

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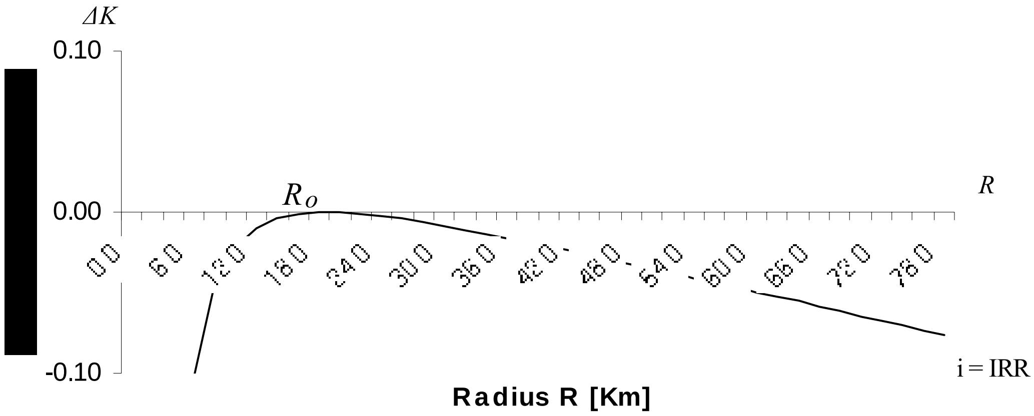

Figure-1. Variation of profitability index ΔK(R), case marginal station ΔK= 0, I = IRR.

The Figure-2 shows a bundle of three different curves corresponding to other solutions for ΔK= f(R). The graph presents the variation of the profitability index as function of radius (R) for 3 cases, ΔK>0, ΔK<0, ΔK= 0.

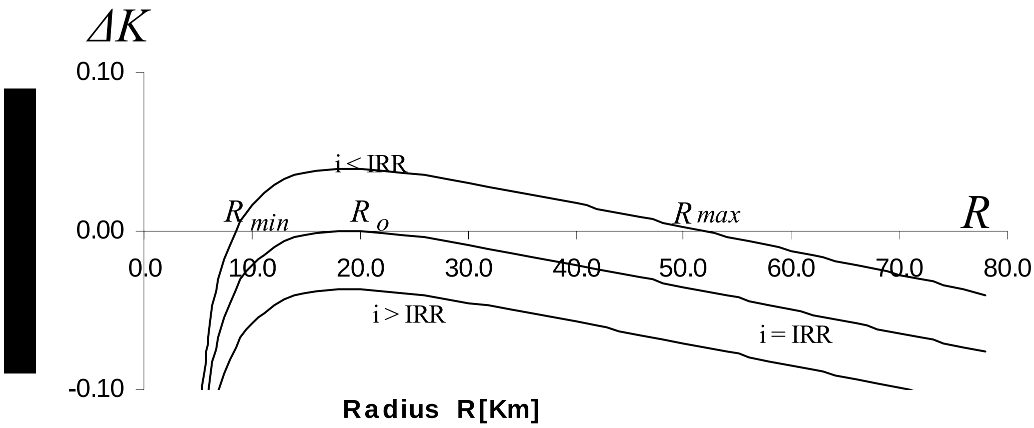

Figure-2. Variation of profitability index ΔK =f(R), ΔK>0, ΔK=0, ΔK<0.

The model fialla adaptation and application

In order to apply the Fialla model, we will have to initially input an assumed bundle of data directly linked with the characteristics concerning the area, the costs, and the EPPP unit. Such data are presented to the Table-1 and they concern the marginal capacity of the EPPP unit.

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Table-2. Input data.

Model for dimensioning of Biomass-fuelled Electric Power plants					
technical data			**economic data**		
Conversion plant			economic parametrs		
Running time	7000	hr/yr	Interest rate	0.15	-
Useful economic life	15	yrs	Discunt factor	5.85	
Ellectric efficiency	0.22	-			
Thermal efficiency	0.624	-			
Utilisation factor	0.5	-			
Maitenance factor per year	0.02	-			
Surface of the area examimated	20.000	km^2			
			Manpower		
			Total employees	6	-
			Averrage wage per capita	12000.0	€/yr
BIOMASS			Limited value		
Net calorific value	4.50	kWh/kg	Ellectrical power	2.0	MW
Cost	40.0	€/tn	Specific plant investement	1600.0	€/kW
Cost of transport	0.25	€/tn · km			
Yield	12.0	tn/km^2			
			energy		
			Selling price of elletricity	0.08	€/kWh
			Selling price of thermal energy	0.0400	€/kWh

Using the data of the Table-1 with respect to the marginal investment cost for ΔK=0 results in this case having an EPPP unit with electric power 4, 3 MW, thermal power 12,2 MW, marginal radius 28,40 km, and total invested capital 14,1 M€. Table-2 presents briefly the results described in previous.

Table-3. Results of the model application with values as Table-1 (marginal investment) ΔK=0.

Results with input data as Table-1, case ΔK = 0 NPV = 0		
Radius of the aria	28,4	km
Surface of the aria	2534,8	km^2
Electric power	4,3	MW
Thermal power	12,2	MW
Specific investment	3267,00	€/kW
Total plant investment	14,1	M€

Note:

-The data input to the model and concern biomass density δ are hypothetical.

-The electrical performance of a steam-powered station n_e is equal to 20-25%, and thermal performance n_t is equal to 60-65%.

-The selling price te of electric power come from biomass for Greece is 73-84, 6 €/MWh (it is almost similar throughout E.U).
-The cost of purchase of biomass κ_{bs} used for energy production is 7 €/tn.
-The transporting cost κ_{ts} varies and depends from the transport means used.
-The number of employees, the technology applied and the type of maintenance influence strongly the cost effective of production and therefore are taken in account.
-Economic parameters like investment costs mean interest rates, and depreciation factors are the average of similar ones being in valid in the E.U.

To the next, the model using the same entry data gives the total of potential investments capable to be viable for the certain area in question. More certain, the model Fialla gives 28 viable investments for EPPP units having power of 1,2 MW that correspond to the minimum radius of the area in question or, the model Fialla gives alternatively 2 viable investments for EPPP units having power o of 20,8 MW that correspond to the maximum radius of the area in question. (See details in Table-4).

Table-4. Results for all feasible investments.

Feasible investments ΔK>0				
	Radius of the aria (km)	**Electric power** (MW)	**Specific investment M€/plant**	**Number of plants**
Marginal investments	28,4	4,3	14,1	8
Minimal investments	15,10	1,2	4,0	28
Maximal investments	62,42	20,8	67,9	2

The initial Fialla model [15] has been adapted for our requirements regarding the sensitivity analysis where the new parameter examined is the variation of the energy produced as a result of the variation in the biomass quality/density available in the area in question. The biomass quality/density seems to influence a high percentage of 20% of the cost effective operation and profitability of the EPPP unit. Therefore, the better density/quality of biomass used, as fuel, the higher efficiency and profitability of the EPPP unit. How can it be done? It can be done persuading the local farmers to grow energy plants. Our approach to this model is to apply it by introducing gradually increasing quantities and qualities of biomass being a part of the total biomass capable to be produced in the area in question. We have applied the model entering gradually increase biomass quantity that can be produced yearly, while all the other parameters are considered as constant, eg: days of yearly operation, life cycle, electrical and thermal power performance, biomass thermal capacity, biomass cost of purchase and transport, mean discount rate, average labour cost, and selling prices of the energy produced. The model adapted as mentioned in previous results that the gradual use of increasing quantity and quality of biomass concludes yields more cost effective and profitable outcomes. Of course, the optimum solution is that which gives the optimum quantity of energy and the highest profits (see the Table-3). Furthermore, the Figures 4 and 5 show how the increase of electrical and thermal power come from the EPPP unit are influenced and change to the same way of the improvement of the density/quality of biomass used as fuel. These results are very useful for the decision makers -public or private organizations - since their task is to choose the optimal solution.

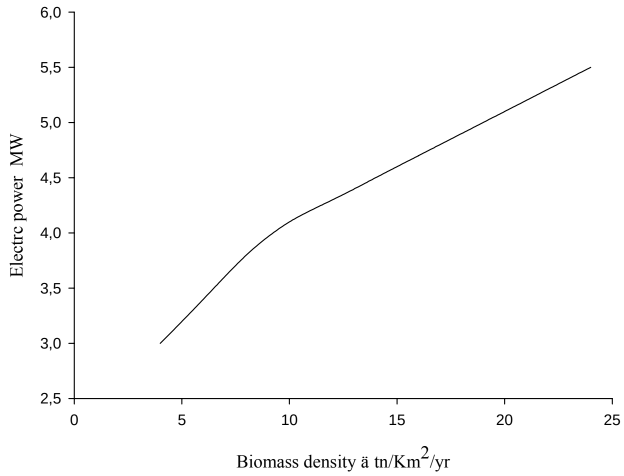

Figure-3. Variation of electric power of the energy station as function of biomass density.

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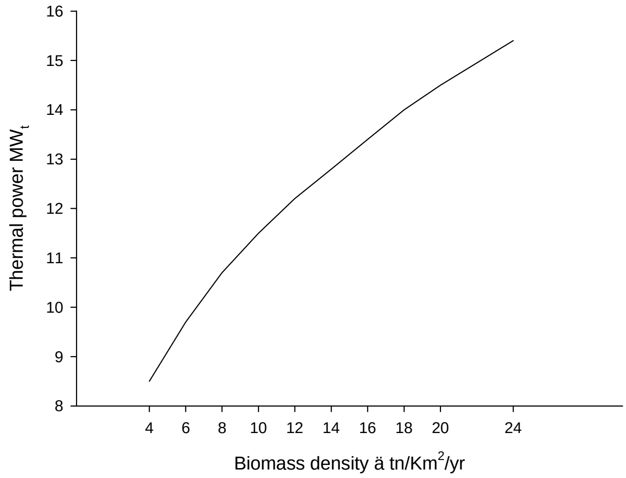

Figure-4. Variation of thermal power of the energy station as function of biomass density.

Also we note that, while the biomass quality/density gradually is increased and improved in a given area, then at the same time, the biomass quantity required to be produced the same quantity of power (kwhs) is decreased by almost the same degree.

The Figure-5 shows the correlation among the radius R of the surface cultivated by energy plants, the biomass density.

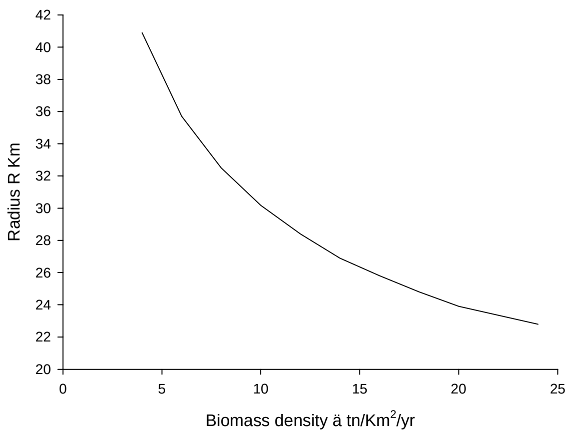

Figure-5. Correlation among radius R of the surface, biomass density.

The environmental dimension of energy production

The adapted Fialla model suggested by us has an advantage since it can take in account and evaluates the potential gas emissions and pollution and, therefore, benchmark the various types of fuel used in the energy production units. The environmental consequences come from the use of biomass and other types of fuel by a power unit in Greece are examined by the model.

The model measures the gas emissions using a factor predefined and so it enables to choose the optimal energy fuel for the power production station or the potential combination of two types of fuel (energy fuel) come from the substitution of a conventional fuel with one that come from renewable sources. Table-5 shows the emissions of polluting gases in a hypothetical power production station that uses two types of fuel - specifically 50% oil and 50% biomass.

Table-5. Gases emitted from power plants.

The environmental impacts from the use biomass as fuel in comparison to the consequences from other types fuelled power plants					
Greenhouse gas emissions factor equivalent CO_2					
1 ton CH_4 =	**21**	**tons CO_2**			
1ton N_2O =	**310**	**tons CO_2**			
Gases emitted in the environment in a power plants					
Fuels		**Emission factor CO_2**	**Emission factor CH_4**	**Emission factor N_2O**	**Greenhouse gas emissions factor**
	(%)	(kg/GJ)	(kg/GJ)	(kg/GJ)	(t_{CO2}/MWh)
Fossil fuel	50,0%	94,6	0,0020	0,0030	0,4915
Liquid fuel		77,4	0,0030	0,0020	0,0000
Gas fuel		56,1	0,0030	0,0010	0,0000
Biomass	50,0%	0,0	0,0320	0,0040	0,0150
Wind		0,0	0,0000	0,0000	0,0000
Energy fuel	100,0 %	47,3000	0,0170	0,0035	0,5065

Thus, if we have for an area the following data, its extent, quantity/quality of biomass produced and the technical-economic data, then the model can estimate:

- If there are the necessary requirements for the establishment at least one EPPP in the certain area
- The surface defined from a circle with the EPPP at its centre
- The electric power produced by the EPPP
- The thermal power produced by the EPPP
- The investment capital required for the various size of EPPP's being viable (specific and total)
- The number of viable cases of EPPP's
- A sensitivity analysis concerning the viable cases of EPPP's
- An analysis of the environmental impacts of the EPPP's

4. Application of the model in the certain area of Kavala

The certain prefecture of Kavala has medium capability to produce significant quantity of biomass capable to be exploited cost effectively by EPPP's, having a density of 12tns/km2/year. Table-4 gives the relevant data.

Table-6. Land using the area of Kavala, in Km$^{2.}$

Land distribution	**Land**	**Agricultural cultivations**	**Forest**	**Other**
Plains	508,5	249,7	30,4	-
Semi-mountainous	638,6	192,6	75,2	-
Mountainous	968.4	116,7	305,6	-
Total	2.115,5	559,0	411,2	1.145,3

The biomass mainly comes from agricultural residues and forest residues.

Table-5 gives data related the economic and technical characteristics of the EPPP suggested and the variables that have been used and finally the optimum minimum capacity - size of EPPP come by the Fialla model carried out.

Table-7. Input data for Kavala's case.

EPPP and biomass characteristics or quality	Quantities	Measuring units
Operation hours/year	7000	hr/yr
Extent of area used for biomass production	2.200	km2
Minimum thermal power of biomass used as biofuel	4,50	kWh/kg
Purchasing cost of biomass	7,0	€/tn
Transportation cost of biomass	0,20	€/tn · km
Biomass density	12,0	tn/km2
Number of employees required for complete operation of EPPP	5	-
Average of annual cost per employee	12000	€/ employee
Lifecycle of EPPP	15	yrs
Electrical performance	0,22	-
Thermal performance	0,624	-
Thermal energy factor	0,5	-
Maintenance factor	0,02	-

We reach the results of Table-8.

Table-8. Outputs of Kavala's case study.

Feasible investments ΔK>0	Radius of the area (km)	Electric power (MW_e)	Thermal power (MW_t)	Number of plants
1.Minimal viable investment	14,19	1,1	3,2	1

The above results conclude that for the certain total area of Kavala Prefecture, there are three possible viable investments for EPPP units having total capacity; a. 3,3 MWe and 9,6 MWt with an investment cost per EPPP unit an amount of 4,9 M€.

It is important to mention that the previous results that come from the application of Fialla model give an initial option of the feasibility for the development of power stations in the certain prefecture of Kavala given the quantity of biomass already existed and come from the today agricultural activities. However, this situation can change significantly since the biomass production can increase-quantity and quality- greatly with the re-organisation of cultivated crops.

CONCLUSIONS

The application of the Fialla model, simplified and amended in this work, concluded that some viable and profitable EPPP units using biomass as fuel can be established and operate in a certain medium extend area having various characteristics. Three of the various solutions resulted by the model are optimal having the best relation among investment cost required, electric and thermal power produced, and performance/profitable. So, an investor has significant options to choose fromto achieve the optimum IRR, opportunity cost, and profit. From a technical/economic aspect and with reference to average American and European conditions, the basic factors for achieving the best economic performance-profit per euro invested for EPPP unit and fix/variable cost/kwh produced- are the thermal energy exploitation factor, which has to be as high as possible. It should be noted that the investment costs for biomass-fuelled EPPP units are almost double-95, 4%- those for modern gas turbine electric-in unit basis of 1 kwh.

Taking in account the previous mentioned results, we can suggest to regional authorities of the prefecture of Kavala that primarily the agricultural residues and secondarily the forest ones already existed can support the establishing and operation an EPPP unit which will use biomass as fuel, having an electric power of 1,1mvh, thermal power of 3,2 MWh. The surface required to produce and provide the quantity of biomass with certain characteristics must have a radius of 14, 19 km or an extension of 200 km2 approximately. So, an individual investor or some state or regional organisation can invest to this opportunity that seems to ensure high and sure profitability.

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