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ELECTRICITY GENERATION FROM BIOGAS ON SWINE FARM CONSIDERING THE REGULATION OF DISTRIBUTED ENERGY GENERATION IN BRAZIL: A CASE STUDY FOR MINAS GERAIS

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KEYWORDS

biodigesters, Normative Resolution 482, swine, energy credits, economic viability.

ABSTRACT

The objective of this study was to analyze the feasibility of using agricultural waste from a swine farm to produce biogas, which can be used to generate electricity. For this purpose, the waste production potential was evaluated to determine the biogas production capacity of the farm. This measurement allowed scaling the size of the generator used to the electricity production to meet the needs of the farm as well as surplus electricity. The surplus electricity may be used on the farm when the generator is under maintenance or the electricity consumption is larger than the energy generated. This process is regulated by Normative Resolutions 482 and 687 in Brazil. The results of the analysis of the net present value, internal return rate, payback period and benefit cost ratio indicated that the project was feasible.

INTRODUCTION

Electricity, although important, is not the main source of expenditure in swine production farm, feed costs, on the other hand, account for 75% of production costs (SEAB, 2013). By contrast, variations in energy costs and uncertainties such as energy availability and quality may make the activity less profitable and less competitive in the international market.

Brazil uses its water resources predominantly to the electricity production (NOGUEIRA et al., 2014). This natural resource is a clean source that produces low-cost electricity but increases the country's dependence on hydrological conditions (KELMAN, 2008). The scarcity of rainfall may cause the need of thermoelectric power plants, in which the cost of electricity generation is much higher, causing increases in tariffs, products, and services for the swine farmers.

Problems related to power distribution in Brazil can be easy by using biogas from swine production. Biofuel gas is produced in anaerobic digesters (SOUZA et al., 2013) known as biodigesters, which are used to ferment animal waste, decreasing the environmental impact, including the emission of air pollutants and contamination of water sources with the swine wastes. This biofuel is flammable and has a high energy content; in addition, it is very similar to natural gas (GOMES & RAIHER, 2013) and can be used for electricity generation.

Biogas is a mixture of gases, and their concentrations are determined by the characteristics of the waste residue and digestion conditions. Biogas contains methane (CH_4), which corresponds to approximately 65% of the volumetric gas composition. The other 35% corresponds mostly to carbon dioxide and other gases (COLDEBELLA, 2008) but in lower concentrations (Table 1).

TABLE 1. Volumetric composition of biogas.

Gas	Chemical formula	Concentration (%)
Methane	CH_4	50–80
Carbon dioxide	CO_2	20–40
Hydrogen	H_2	1–3
Nitrogen	N_2	0.5–3.0
Sulfuric gas and other gases	H_2S, CO, NH_3, H_2O	1–5

Source: (COLDEBELLA, 2008).

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Combustion engines that use biogas are the most feasible on a commercial scale considering the low installation cost, simplicity, and ease of maintenance. The power output of these engines varies from 10 to 150 kW, and the efficiency ranges from 15% to 35% (SALES et al., 2005).

The transformation of the chemical energy of biogas into electrical energy is effective in these devices (OLIVEIRA, 1997), which burn a mixture of air and biofuel and transform thermal energy into mechanical energy.

Besides biogas, any other renewable energy source for the generation of electricity is allowed in the net metering distribution generation law, which was implemented in Brazil, in April 2012 through Normative Resolution 482. According to this resolution, the electricity injected into the local grid by a consumer unit using renewable energy sources, with distributed micro-generation (installed capacity ≤100 kW) or mini-generation (installed capacity >100 kW and <1 MW), is transferred through a free loan to the local electricity provider. Subsequently, the distributed generation unit is compensated with the credit to use electricity from the same unit or other units from the same owner. Furthermore, the farms should be in the concession area of the same electrical utility, and the credits should be valid (they expire after 5 years of the generating date). The RN 487 was updated by RN 687 in November 2015. The main changes brought by RN 687 were the increase in the period of use of energy credits from 3 to 5 years and an increase of the maximum output to 5 MW in cases of mini-generation (ANEEL, 2012, 2015).

The objective of this study was to evaluate the economic feasibility of electricity generation from biogas on a swine farm considering the regulation of the power generation in Brazil. The specific objectives were to evaluate the biogas production potential on a swine farm; to scale the size of the biodigester used for processing the waste; to determine the initial cost of the equipment; and to analyze the feasibility of using the current federal regulation and to obtain data from the studied farm.

MATERIAL AND METHODS

Biogas production potential

The generation of electricity in swine farms was estimated by determining the potential for biogas production. This potential was evaluated after analyzing the amount of waste produced on the farm in one year, which depends on the number of animals on the farm, mortality rate, confinement period, and the amount of waste generated by each animal in one day (PRATI, 2010) according to [eq. (1)].

$$\mathrm{D_{pa}} = \mathrm{N_a}(1 - \mathrm{M_o})\mathrm{D_{da}}\mathrm{N_{dc}}\mathrm{F_c} \tag{1}$$

Where,

$\mathrm{D_{pa}}$ = waste produced per year (m³);

$\mathrm{N_a}$ = number of animals;

$\mathrm{M_o}$ = mortality (%);

$\mathrm{D_{da}}$ = waste (m³) produced per animal per day;

$\mathrm{N_{dc}}$ = number of confinement days in one year (days), and

$\mathrm{F_c}$ = correction factor for uncertainties.

Equation 2 was used to estimate the daily amount of waste produced ($\mathrm{D_{pd}}$) on the farm:

$$\mathrm{D_{pd}} = \mathrm{D_{pa}}/365 \tag{2}$$

Equation 3 was used to determine the total volatile solids produced in one day by the amount of waste generated daily:

$$\mathrm{V_{SV}} = \mathrm{D_{pd}}\mathrm{V_{ST}}\mathrm{P_{SV}} \tag{3}$$

Where,

$\mathrm{V_{SV}}$ = total volatile solids in the waste (kg);

$\mathrm{V_{St}}$ = total solids in the waste (kg/m³), and

$\mathrm{P_{SV}}$ = percentage of volatile solids in total solids (%).

The volume of biogas (in m^3) generated per day ($\mathrm{V_{bg}}$) was calculated using [eq. (4)], which is a function of the biogas volume that can be generated from each kilogram of volatile solid ($\mathrm{B_{SV}}$):

$$\mathrm{V_{bg}} = \mathrm{V_{SV}}\mathrm{B_{SV}} \tag{4}$$

Sizing the biodigester

To design the anaerobic lake, it is necessary to consider the hydraulic retention time that will be used in the biodigester and the daily volume of waste produced, as established in [eq. (5)]. According to OLIVEIRA (1993), the optimal retention time for swine waste is 22 days.

$$\mathrm{V_{bd}} = \mathrm{T_{rh}}\mathrm{D_{pd}} \tag{5}$$

Where,

$\mathrm{V_{bd}}$ = volume of the anaerobic reactor (m³); and

$\mathrm{T_{rh}}$ = hydraulic retention time of the reactor (days).

Feasibility analysis

The feasibility of project implementation was analyzed in the life cycle of the generator which was considered to be 10 years according to CERVI et al. (2010).

The minimum rate of attractiveness (MRA), which represents the minimum rate of return on investment (TORRES, 2004), was considered to be equal to the interest rate applied by the Caixa Econômica Federal (a Brazilian government bank) in the Credit Investment Program for rural producers, which is 6.5% per year.

It was expected that electricity generation reduces the expenditure with electricity considering the generator operating time in one year.

Operating costs are based on the costs of operating the biodigester and generator, including labor.

The feasibility of the investment can be evaluated using economic indexes such as the net present value (NPV), internal return rate (IRR), and benefit-cost ratio (BCR).

Net Present Value

The NPV corresponds to the sum of all entries in the cash flow discounted from the MRA and the initial investments. This variable indicates how much future payments plus an initial cost would be worth today (BARROS, 2013) and is calculated using [eq. (6)].

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{\mathrm{FC_t}}{(1+i)^t} \tag{6}$$

Where,

$\mathrm{FC_t}$ = cash flow in year t (R$);

t = year corresponding to cash flow (year);

i = interest rate considered, in this case the MRA (decimal), and

n = project lifetime (years).

Internal Return Rate

The IRR corresponds to the interest rate capable of zeroing the investment NPV (BARROS, 2013) and is calculated using [eq. (7)].

$$0 = \sum_{t=1}^{n} \frac{\mathrm{FC_t}}{(1+\mathrm{IRR})^t} - \mathrm{I_0} \tag{7}$$

Where,

IRR = return rate, decimal, and

$\mathrm{I_0}$ = initial investment (R$).

Benefit Cost Ratio

This indicator represents the return provided for each unit of capital invested. Therefore, for an investment to be viable, the BCR should be larger than one (RODRIGUES et al., 2007). The BCR is calculated using [eq. (8)].

$$\mathrm{BCR} = \sum_{t=0}^{n} \frac{\mathrm{B_i}(1+i)^{-t}}{\mathrm{C_i}(1+i)^{-t}} \tag{8}$$

Where,

$\mathrm{B_i}$ = project benefit in Brazilian reals in year t, and

$\mathrm{C_i}$ = cost of the project in Brazilian reals in year t.

Data of the studied farm

The studied swine farm had 800 sows. The farm operated in complete production type, that integrated: reproduction, maternity and termination phases; and the feed factory. The electrical utility provided the average hourly power consumption for the period from September 2013 to September 2014 (Figure 1).

The average daily electrical energy consumption was 907 kWh in off-peak hours and 46 kWh in peak hours. The peak demand in the study period was 110.68 kW. The electricity consumption was highest in August 2014 (35,547 kWh).

CEMIG's electricity tariffs in September 2015 are presented in Table 2.

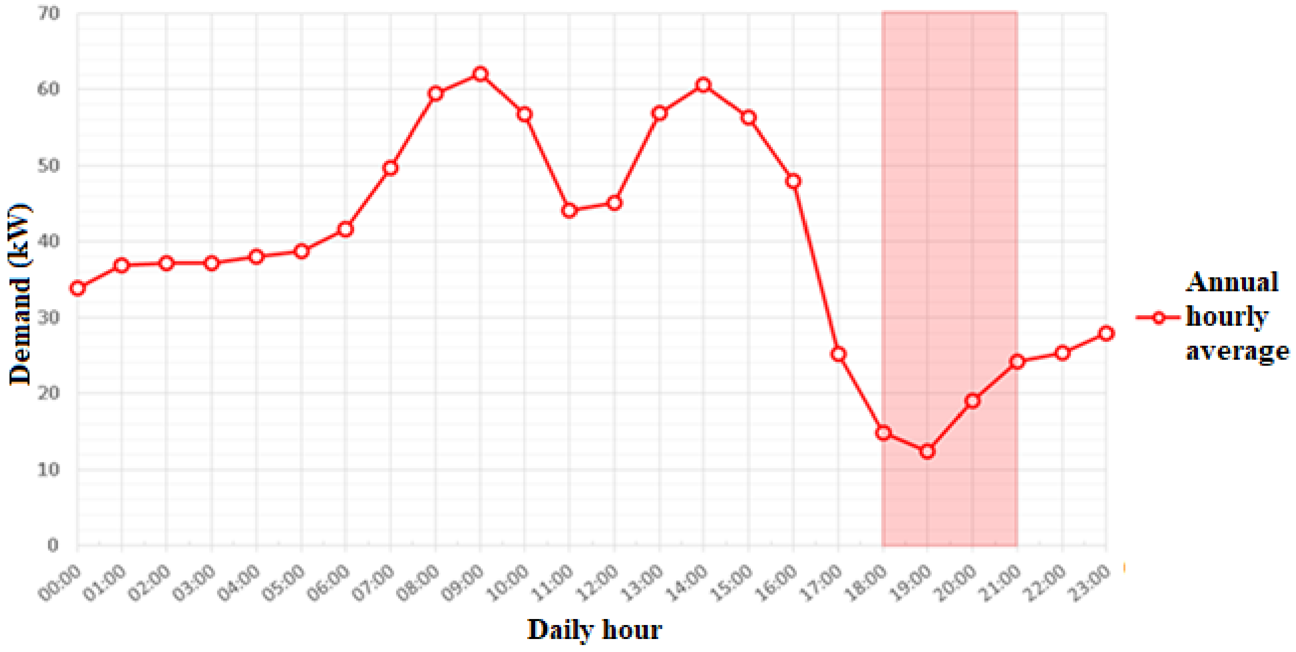

FIGURE 1. Average hourly electricity consumption in the studied farm for the period from September 2013 to September 2014.

TABLE 2. Electricity tariffs of CEMIG in September 2015.

	Demand (R$*/kW)		Exceeding demand (R$/kW)		Consumption (R$/kWh)	
	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
THSA	28.98	8.28	57.96	16.56	0.41861	0.28640
THSV	9.00		18.00		1.22998	0.36476
Conventional	29.14		-		0.29742	
B2	-		-		0.30677	

Source: (CEMIG, 2015).
*US$1.00 = R$ 3.96 in September 2015

The property adopted the green hourly seasonal tariff, that is a time of day electrical rate - with only two daily periods, peak and off- peak ones, with 120 kW of contracted demand.

RESULTS AND DISCUSSION

Sizing the generator

Thus, a 120-kVA generator is necessary for supply the energy needs of the farm.

After analyzing the electricity consumption of the property, it was necessary to determine the costs of the equipment for installing the distributed generation on the farm. According to the manufacturer ERBR Renewable Energies, it is necessary to consider the costs of a 120-kVA generator, including the cost of electrical protection equipment, network connection, and the biogas purification system (Table 3).

TABLE 3. Cost of 120 kVA electricity generation equipment.

Cost of generation equipment	
Equipment	**Cost (R$)**
Electrical energy generator 120-kVA	147,137.00
H_2S filter up to 1500 ppm	15,900.00
Protection panel	42,245.00
Auxiliary equipment for offline operation	7,870.00
Starting equipment	8,900.00
Total	222,052.00

According to ERBR Renewable Energies, the maintenance cost of the selected generator was R$ 3.19 per hour of operation, and the biogas consumption of the generator was 42 m³/hour. The energy output of the equipment was 76.8 kWh per hour adopting an operation with more than 3 hours per day.

Connecting the power plant to the electricity grid of the electrical utility requires the purchase of connection equipment, which costs approximately R$ 75,000.00 for a 120-kVA generator (data from SEPI Engineering).

The estimated cost of installing a biodigester is R$ 150.00 per m³ of the anaerobic lake (PRATI, 2010), and the cost of annual maintenance is 2.5% of the initial investment (MARTINS & OLIVEIRAS, 2011).

The initial investment required for installing the power generation plant is detailed in Table 4.

TABLE 4. Cost of installing the 120 kVA power generation plant.

Equipment	**Cost (R$)**	**Percentage**
Generator 120-kVA	147,137.00	29.19
H_2S filter up to 1500 ppm	15,900.00	3.15
Protection panel	42.245,00	8.38
Auxiliary equipment for offline operation	7,870.00	1.56
Starting equipment	8,900.00	1.77
Network connection	75,000.00	14.88
Biodigester installation	207,009.00	41.07
TOTAL	**504,061.00**	**100.00**

Potential of biogas production in the evaluated swine farm

For the complete cycle production system, which was adopted in the studied property, the number of confinement days of the animals (N_{dc}) was considered to be 365 days per year, and the average volume of waste produced by the swines (D_{da}) was 0.0086 m³. The maximum mortality rate (M_o) tolerated was 3%, and the adopted uncertainty factor (F_c) was 0.94 (PRATI, 2010). There were 8,000 animals on this farm, and 10 animals were estimated per sow (FERRAREZ et al., 2014).

The results of [eq. (1)] indicated that the volume of waste produced in one year was estimated in 22,897.12 m³. According to equation 2, the amount of waste produced per day (D_{pd}) was 62.73 m³.

The total volatile solids in waste material reported in different studies vary between 8.514 kg/m³ and 90 kg/m³, and the percent volatile solids range from 70% to 75%. The lowest value for the percent volatile solids and a value of 55 kg/m³ for the total volatile solids were used to increase the safety to the swine farmer and avoid oversizing, as recommended by PRATI (2010).

The results by using equation 3 indicated that the total volatile solids present in one day was 2,415.18 kg.

The reported amount of biogas generated per kg of volatile solid ranges from 0.45 m³ to 0.78 m³ (PRATI, 2010), and the lowest value was used to increase the safety to the swine farmer. The results of equation 4 indicated that the property produced around 1,086.83 m³ of biogas per day.

Electricity generation

If connected 18 hours a day and 30 days a month, this generator can produce 41,472 kWh of electricity per month, demonstrating that adopting the proposed distributed generation system allows accumulating at least 5,925 kWh of energy credits from the power plant every month compared with the electricity generated in the month of highest consumption in the analyzed period. These credits can be used when the generator needs to be disconnected for maintenance or in case of extra load be connected in the farm, by any reason. Therefore, in each year of operation of the generator, it is possible to earn at least two months of credits, i.e., considering a useful life of 10 years of continuous use. Since the equipment could be used for another 20 months or 1.66 years, the life span of the project would be 11.66 years.

Operating costs

The operating costs are based on the cost of keeping and operating the biodigester and generator. For this purpose, the value of one minimum wage (R$ 788.00 quoted in September 2015) was added monthly for maintenance costs of the biodigester and generator.

The maintenance and operating costs of the generator was R$ 3.19 per hour (data provided by ERBR Renewable Energies). These data were used to calculate the amount spent on generator maintenance, and the annual operating cost of the generator was R$ 30,414.30. For biodigester maintenance, the estimated annual cost of operation was 2.5% of the initial installation cost (MARTINS & OLIVEIRAS, 2011) plus a monthly minimum wage (R$ 788.00, quoted in October 2015) for an employee to operate the biodigester. The annual expenses calculated with maintenance are shown in Table 5.

TABLE 5. Annual maintenance costs.

Equipment	**Annual cost (R$)**	**Percentage**
Generator	30,414.30	67.52
Biodigester	14,631.23	32.48
Total	**45,045.53**	**100.00**

To ensure the power supply by the electricity provider, it is necessary to pay at least, the electrical demand costs, equivalent to the nameplate value, i. e 120 kVA. In our case R$ 9.00/kW (Table 2); therefore, the annual demand costs would be R$ 12,960.00. The generation equipment may have a residual value at the end of its useful life; however, in this study, the worst scenario for the residual value of the generator was considered (R$ 0.00) to increase the safety margin of the results of the economic analysis. The total annual cost to operate the equipment would be R$ 58,005.53.

Cash flow

The savings generated by avoiding the consumption of electricity provided would be considered as input into the cash flow of the farm. Therefore, as the farm adopts time of use rate, with a monthly average consumption of 907 kWh in off-peak hours and 46 kWh in peak hours, the savings will be R$ 139,469.90 per year.

The cash outflows are the sums of the expenses with initial investments or equipment and the operational costs.

The cash flow of inputs and outputs is shown in Figure 2.

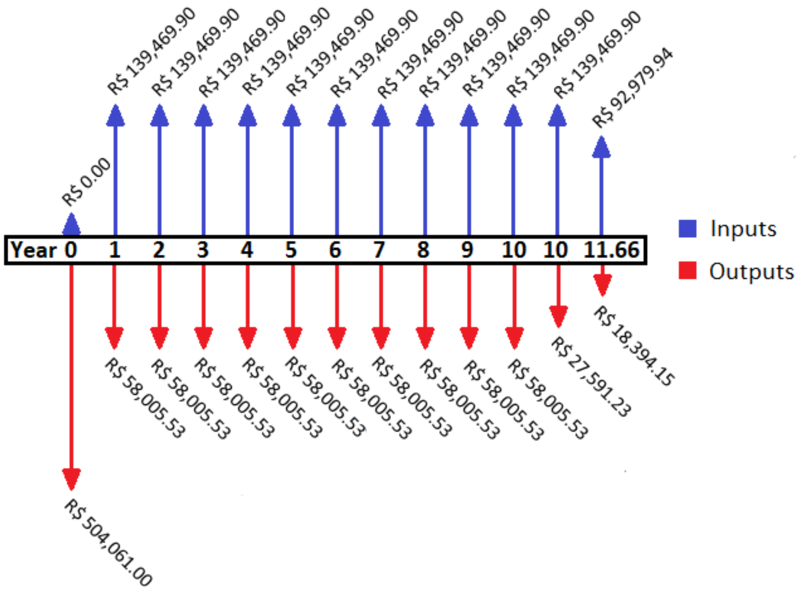

FIGURE 2. Cash flow in the period of use of the 120 kVA power generation equipment.

In this cash flow, the last 20 months or 1.66 years represent the period that the generator can be switched off to use the energy credits, which should not be used at the end of the generation equipment life because the credits expire after 5 years of its installation, Figure 2. That means the energy credits must be used before it expires. Note that maintenance costs and generator depreciation were not included in the cash flow outputs in these months.

Feasibility analysis

After collecting data and analyzing the cash flow, an economic evaluation is necessary to make the decision and to assess whether it is feasible to make such investment, as presented in Equations (6), (7), and (8).

The results of the feasibility analysis are shown in Table 6.

TABLE 6. Results of the feasibility analysis.

Feasibility analysis	
Minimum rate of attractiveness	6.5% per year
Net present value (6.5% per year)	R$ 173,325.51
Internal return rate	12.32%
Benefit cost ratio	1.44
Total net revenue	R$ 497,047.26
Payback period	8.21 years

The project was viable (Table 6) and generated a profit starting in month 98, with total net revenue of R$ 497,047.26 during the analyzed period. This amount is decreased to R$ 173,325.51 in current values because of currency devaluation, demonstrating that for each real invested, the farmer’s return was R$ 1.44, and the IRR was 12.32%, which was higher than the minimum rate of attractiveness for the investment. The payback period was 8.21 years, indicating that the investment was paid before reaching the useful life of 10 years. The lower is the payback, the more attractive is the investment.

Sensitivity analysis

For higher reliability of the obtained results, a sensitivity analysis was conducted since changes in the economic scenario regarding investments and costs might occur. The sensitivity analyzes was performed for variations in electricity and equipment costs. For these analysis new scenarios, the minimum rate of attractiveness was kept constant.

Energy costs

We analyzed four cases in which the cost of electricity was higher or lower than current values:

1. 20% lower than current values;
2. 10% lower than current values;
3. 10% higher than current values, and
4. 20% higher than current values.

The following economic analysis results were obtained (Table 7).

TABLE 7. Sensitivity analysis results for electricity costs.

Sensitivity analysis of current electricity costs				
Variation	-20%	-10%	10%	20%
NPV (6.5% per year)	R$ -29,316.57	R$ 72,004.47	R$ 274,646.54	R$ 375,967.58
IRR (%)	5.42%	8.98%	15.48%	18.52%
BCR	1.18	1.31	1.56	1.68
Total net revenue	R$ 201,857.48	R$ 349,452.37	R$ 644,642.14	R$ 792,237.03
Payback period	-	10.2 years	6.8 years	5.8 years

The project was unfeasible in cases in which the current costs of electricity were decreased by 20% and feasible when prices were at least 90% of the current prices in the market.

Equipment costs

The cases in which equipment costs differed from current prices were also analyzed, as follows:

1. 40% lower than current values;
2. 20% lower than current values;
3. 20% higher than current values, and
4. 40% higher than current values.

The following results were obtained (Table 8).

TABLE 8. Sensitivity analysis results for equipment costs.

Sensitivity analysis for current electricity costs				
Variation	-40%	-20%	20%	40%
NPV (6.5% per year)	R$ 361,529.13	R$ 267,427.32	R$ 79,223.69	R$ -14,878.12
IRR (%)	23.25%	16.86%	8.85%	6.08%
BCR	1.74	1.58	1.33	1.23
Total net revenue	R$ 692,822.71	R$ 594,934.98	R$ 399,159.53	R$ 301,271.81
Payback period	4.7 years	6.3 years	10.2 years	-

Large increases in equipment costs make the investment unfeasible if other variables are kept constant, including the cost of electricity and the minimum rate of attractiveness.

CONCLUSIONS

The present study analyzed the feasibility of adopting the distributed generation of electric energy in a swine farm by using the biogas generated from swine waste and applying the electrical energy regulatory agency resolutions 482 and 687 that revenue profit from energy credits.

The project was viable, with a net present value R$ 173,325.51, internal return rate of 12.32%, and benefit cost rate of 1.44. Only the savings generated by using the electricity from the electric utility were considered. However, the farmer may make profit from other products, including the sale of biofertilizers from biodigester effluents and the return of the clean development mechanism to obtain income by decreasing the emission of pollutants in the atmosphere as proposed by the Kyoto protocol, if it comes back to be effective.

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