Original Article

An Optimal Bi-Objective Study For A Broiler Production Network

Tahraoui Nacera[1], Triqui-Sari Lamia[2], Bennekrouf Mohammed[3]

[1,2] Manufacturing Engineering Laboratory of Tlemcen (MELT)-Algeria
[3] ESSA Tlemcen-Algeria
Email: [1] naceratahraoui@hotmail.com, [2] triquilamia@yahoo.fr, [3] mbenkrouf@gmail.com

*Corresponding Author: Tahraoui Nacera
Manufacturing Engineering Laboratory of Tlemcen (MELT)-Algeria
Email: naceratahraoui@hotmail.com
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Abstract

In this work, we study the first level of poultry network which contained several farms (poultry houses) dedicated to broiler breeding. For breeding the necessary conditions must be respected, using good feeding, veterinary care, adequate ventilation and ambient heating which may be gas or electric etc. The problem of this network is the installation of the heating system, more precisely the main problem is to choose between a gas or an electric heater. Knowing that the gas heating has a low cost but a rather high emission of carbon dioxide which is harmful for the liveliness of chickens and the environment in general, on the other hand, the electric heating is very recommendable because of the low rate of resignation of CO2, that said its high cost hinders considerably the breeders. To find an intermediate solution that minimizes the different costs while respecting the environmental aspect we propose in this work a multi-objective mathematical modelling that minimizes the heating costs and minimizes the carbon dioxide emissions. Both objectives are optimized independently, then after LP-metric aggregation is used to combine them to find the optimal solution.

Keywords: CO_2 emissions, energy costs, LP metric method, optimization

I. INTRODUCTION

Broiler farming is a widespread activity, for several reasons: the short breeding period, the availability of the meat in the markets, and its price which is relatively low compared to other meats. (Satır and Yıldırım, 2020; Tahraoui *et al.* 2020) [**1**][**2**]. However, for this activity to be successful, certain requirements must be met and the environment must be adequate to obtain good-quality chickens (Petracci *et al.* 2015) [**3**]. To do this, farms must have a breeding capacity that cannot be exceeded, conforming materials, availability of feed and water, veterinary care, good breeding space, and a mandatory ambient heat that ensures the survival of the chicks, without any influence on the liveliness of the chicken.

Farm heating is an important element in broiler breeding, since broiler chicks cannot regulate their temperature, and thermal disturbance can affect the physiological balance (health and performance) of the chickens. For this reason, broiler houses should be equipped with heating systems specified according to the breeding standards. This heating system provides the right temperature within the farm, allowing the chickens to move around the barn and to feed and drink, therefore ensuring the proper fattening of the broilers.

In Algeria, chicken farming is generally practiced in traditional farms, which use butane gas heaters for heating systems, which emit a lot of carbon dioxide and have a significant impact on the environment. This has prompted farmers to seek to introduce low-CO2 heating systems using electric heaters, but the problem is that they are very expensive, which reduces farmers' profits. In this context, two heating systems can be distinguished: the traditional ones, provided by butane gas heaters, with high CO2 emissions but low energy costs. The second is electric heating, with lower carbon dioxide emissions, but high energy costs.

In this study, we considered a broiler breeding network in the city of Tlemcen in Algeria, which consists of a set of chicken farms and a slaughterhouse. The problem with this network is the confusion of farmers in the choice of the gas or electric heating system.

II. STATE OF THE ART

Our study focuses on a bi-objective study of broiler production planning to satisfy a given demand. The objective is to minimize the CO_2 emissions of the network farms and the sum of the heating energy costs at the same time. So the literature review is based on three parts, the first one concerns the poultry supply chain, the second one presents the work related to cost estimation of the heating systems used in the breeding farms, and the third one concerns the studies of the CO_2 emissions at the breeding farms.

The poultry supply chain, more specifically broiler breeding, has attracted the attention of several researchers in different fields of research: biology, statistics, and production planning. Among these researches, a statistical study on broiler production in Turkey is presented by (Demir *et al*. 2010) [**4**]. Then for the biological study (Petracci *et al.* 2015) [**3**] present the best solution about fast growth of broilers. (Brevik *et al.* 2020) [**5**] propose integrated planning for the allocation of different fertilized eggs from hens of different ages to chicken farms to maximize broiler quality.

Breeding chickens is carried out in farms equipped with material resources, these resources consume a lot of energy and require special management. That motivates many researchers to study the energy consumption in chicken production networks like (Overhults 2017) **[6]** carry out a comparative analysis of the yearly heating costs of two various heating systems, one with natural gas and the other with wood pellets. (Hanifah, *et al*. 2018) [**7**] conducted an economic study where the operating costs of heating poultry houses is investigated. Also for financial energy point of view, (Costantino *et al.* 2021) [**8**] presents the optimal type of insulation in each farm to get the best energy to be used. (Heidari, *et al.* 2011) **[9]** adapt a methodology to estimate energy consumption for broiler production.

The CO_2 emissions from poultry farms depend on the number of chickens reared and the rearing equipment installed in the building. Environmentalists have determined a threshold level of CO_2 emissions to be respected, which prompted researchers to determine the CO_2 emissions for each type of farm and each type of equipment used for breeding. Such as (Sadiq, and Singh, 2017) [**10**] make a comparative study on CO_2 emissions between productive and non-productive farms. (Kapica et al. 2015) [**11**] they study the adaptation of heating systems using renewable energy on broiler farms to minimize CO_2 emissions. (Pereira 2017) [**12**] established a study to measure the rate of gas emissions from broiler farms.

From the synthesis of the different works cited, we have observed that the majority of the studies have made a mono-objective optimization. However, to reflect the practical reality, the different costs with the impact of CO_2 emissions offers more visibility and actions on such environmental problems. Therefore, we were interested in studying the problem in a bi-objective context, taking into account both the environmental aspect and the concept of energy cost.

III. PROBLEM DECRIPTION

In this study, we considered a network of broiler farms ($i \epsilon I$) situated in the city of Tlemcen in Algeria, these farms grow broilers to a high weight in a breeding period consisting of 45 days of chicken fattening and a mandatory sanitary vacuum month. These farms supply a slaughterhouse that supplies a defined number of distributors, who sell the white meat to consumers in the network studied.

The problem in this network is the choice of the type of heating system used during the breeding season. There are two types of heating systems: gas and electric. In the gas heating system, the farmer uses a heating system based on the use of butane gas, the cost of this type is cheaper but the problem is that the used heaters have a high rate of CO_2 emissions that comes from the gas-burning, the resulting emissions mainly affect the environment. In contrast, the electric heating system uses electric heaters, noting that the electricity cost is very high and affects the profit of the farmers but the CO_2 emissions are too low.

The challenge of this study is to develop a bi-objective mathematical model, which combines the two objectives: minimisation of CO_2 emissions, and minimisation of energy costs.

Mathematical modeling

In this section, the model is formulated in Mixed Integer Linear Programming for both objectives, where the sets of model are respectively: farms (i) which contain 60 farms, one slaughterhouse and two types of heaters(t) that means electrical or gas choice between them. In reality practice the considered hypotheses are presented as follow:

- For each breeding center (i), a lower and an upper capacity limit of the numbers of chickens bred must be respected for both energy sources.
- Before starting breeding at each farm (i) and for each breeding period, only one type of energy source should be chosen Each farm produces only one breeding band throughout the production horizon
- The CO_2 emission rate varies linearly with energy consumption in electric or gas form

Parameters

Sets

i : set of breeding farms i ϵ I.
t : types of heaters used for breeding t ϵ T.

parameters

$ECO2_{it}$: the CO_2 emission factor of each farm i according to the type of heating used t.
CE_{it} : the energy cost depends on the type of heating t used in each farm i.
CFX_{it} : the maximum number of chickens on the farm i for each type of heating t.
CFN_{it} : the minimum number of chickens in farm i for each type of heating t.
$QPCH_{it}$: the number of chickens per heater on each farm i according to the type of heater used t.
A: a large number
S: The CO_2 emission threshold for each farm
D: The slaughterhouse demand.

Decision variables

QP_{it} : the quantity of produced chickens in farms i using heating type t.
NCH_{it}: number of heaters within each farm i using heating type t.

$$X_{it} = \begin{cases} 1 & \text{if farm i is chosen for breeding using type of heating t.} \\ 0 & si\ non \end{cases}$$

IV. RESOLUTION APPROACH

To solve this problem, we developed a mathematical model for three different configurations: minimization of energy costs, minimization of CO_2 emissions, and the combination of the two objectives using the LP metric method.

1. *The 1st configuration: minimization of energy costs*

The city of Tlemcen is located in the west of Algeria and is populated by more than 200,000 habitants. In this area, the chicken consumption is important, so the challenge is to choose the best decision on the mode of production by focusing on the choice of energy source in the potential set of farms. These farms are denoted i (iϵI) and supply a single potential slaughterhouse whose demand must be fully met at time horizon level.

In this configuration, the objective is to minimize the sum of the global energy cost of heating within all networks farms, as given by equation (1).

$$\min F1 = \sum_i \sum_t QL_{i\ t} * CE_{i\ t} \qquad \textbf{(1)}$$

Under the constraints

$$\sum_t X_{i\ t} \leq 1 \qquad \forall i \qquad \textbf{(2)}$$

$$QP_{i\ t} \leq CFX_{i\ t} * X_{i\ t} \qquad \forall i\ \forall t \qquad \textbf{(3)}$$
$$QP_{i\ t} \geq CFN_{i\ t} * X_{i\ t} \qquad \forall i\ \forall t \qquad \textbf{(4)}$$
$$QP_{i\ t} \leq A * X_{i\ t} \qquad \forall i\ \forall t \qquad \textbf{(5)}$$
$$QP_{i\ t} \geq X_{i\ t} \qquad \forall i\ \forall t \qquad \textbf{(6)}$$
$$QP_{i\ t} = NCH_{i\ t} * QPCH_{i\ t} \qquad \forall i\ \forall t \qquad \textbf{(7)}$$
$$\sum_{i} \sum_{t} QP_{i\ t} = D \qquad \textbf{(8)}$$
$$X_{i\ t} \in \{0\ ,1\} \qquad \forall i\ \forall t \qquad \textbf{(9)}$$
$$QP_{i\ t} \in R^{+} \qquad NCH_{i\ t} \in N \qquad \forall i\ \forall t \qquad \textbf{(10)}$$

Constraint (2) ensures that the chicken farms i are opened using a single heating system t. Constraints (3) and (4) ensure that the number of chicks bred within each farm i must respect the maximum and minimum capacity of the farm. Constraints (5), (6), and (7) calculate the number of chicks bred and the number of heaters used on each farm i. Constraint (8) ensures that the total demand for the slaughterhouse is satisfied. Constraints (9) and (10) indicate the binary and the real nature of the decision variables.

2. The 2nd configuration: minimising CO2 emissions

This part focuses mainly on the environmental context, the objective is to study the impact of CO2 emissions and their evolution while proposing techniques and a model to reduce them. Equation 11 explain this second objective mathematically. In addition to keeping all the constraints of the first configuration, concerning cost reduction, we add constraint 12 stipulating the limit of not exceeding an emission threshold S.

$$\min F2 = \sum_{i} \sum_{t} QL_{i\ t} * ECO_{i\ t} \qquad \textbf{(11)}$$
$$ECO2_{i\ t} * NCH_{i\ t} \leq S \qquad \forall i\ \forall t \qquad \textbf{(12)}$$

3. The 3rd configuration: adaptation of LP-metric method

Jointly, this configuration proposed by a multi-objective decision making model aims to manage the conflict between both objectives. the reduction of CO2 emissions in relation to the variability of heating source choice may increase the cost which presents an economic disadvantage where the conflict will occur and weights must be used to find the best compromise interval.

In the literature, the LP metric method has been the subject of several multi-objectives researches. Such us, (Arabzad *et al* .2015) **[13]** studies a location-allocation problem in a bi-objective context: minimization of total costs and minimization of deterioration rate due to transportation using the LP metric method. Similarly, (Gharaei *et al*. 2017) **[14]** have optimised by minimizing the storage costs and maximizing the total profit of a value chain by LP-metric method as well. Similarly, in the work (Tahraoui *et al.* 2021) [**15**] another bi-objective case has been discussed that is minimizing energy consumption in conflict with maximizing the produced chicken's quality. For this purpose, we have adapted it to solve our bi-objective oriented problem: cost minimization and CO2 emissions reductions.

Equation 13 combining the two contradictory objectives corresponds to the weight variation w_i between 0 and 1 according to the principle of the LP metric method. The objective of this method is to calculate the homogeneous sum of the objective functions (without units) knowing that the sum of all weights must be equal to 1. under all constraints (2 to 10, and 12).

$$\min FP = w_1 * \frac{F1 - F1_{optimal}}{F1_{optimal}} + w_2 * \frac{F2 - F2_{optimal}}{F2_{optimal}} \qquad \textbf{(13)}$$

V. NUMERICAL APPLICATION

In this numerical validation section, the network is composed of 60 farms units that supply a single slaughterhouse. Knowing that intervals of farm capacity are to be respected with constraint of a CO2 emissions threshold limit. 8 scenarios of demands satisfaction analysis as presented in Table 1 are to be analysed and interpreted.

Table 1: The Demands Of The Slaughterhouse.

Scenario	Demand	Scenario	Demand
1	140 000	**5**	350 000
2	192 500	**6**	402 500
3	245 000	**7**	413 000
4	297 500	**8**	420 000

The numerical parameters used for our modelling are collected from the questionnaires given to the different types of livestock farms in the network studied in the city of Tlemcen in Algeria,

The data relating to the farms such as minimum and maximum livestock capacity, the cost of each type of heating, and the rate of CO2 emissions are presented in Table 2.

Table 2: The Data Related To The Farms.

	Gas heaters	Electric heaters
The minimum breeding capacity	2 000	2 000
The maximum breeding capacity	7 000	7 000
The cost of heating	5 000	24 500
The carbon dioxide emissions rate	14 000	4 000

VI. RESULTS AND DISCUSSION

To solve this medium instance problem, we validated the developed model on Cplex. To see the effect of demand on the choice of energy sources, the opening or closing of farms and the quantities to be produced at each farm, a sensitivity analysis by scenarios was presented.

In the first part, a comparison of the three configurations was made: mono-objective cost, mono-objective environment, and a multi-objectives cost-environment. In the second part, the weighting coefficient was varied in the LP metric method to find the best pair of compromises.

Comparison of the three proposed configuration

To show the interest of our contribution, the three results of the heating costs and CO2 emissions in relation to the two single-objective visions and the coupled multi-objective vision are presented and compared in the following figures (1 and 2).

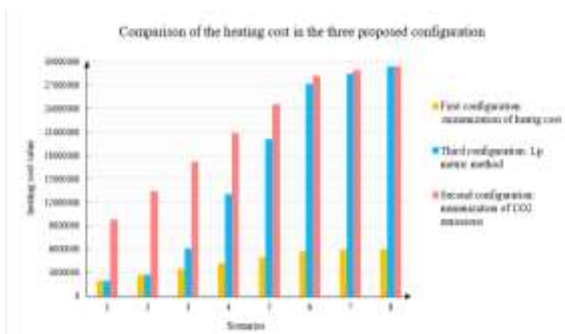


Fig.1: Comparison of the heating cost in the three proposed configurations.

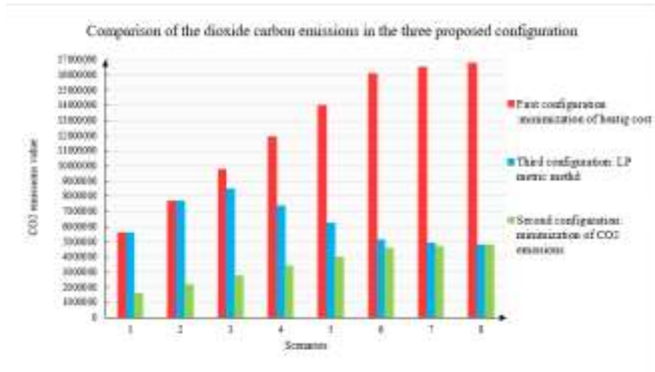


Fig.2: Comparison of the CO2 emissions in the three proposed configurations.

As the consumption due to heating has an important part in the energy cost balance, we can say that our analysis technique is beneficial to imply the impact of CO2 emission reduction in the poultry network. However, LP metric aggregation approach allows to justify the trade-off limits via the comparison with the independent results of single-objective approaches.

In relation to the dominance of the configurations, we observe that in the scenarios (1 and 2) relating to the cases of low demand, the solutions obtained by the LP metric method tend practically towards the first configuration, i.e. that of reducing heating costs. On the other hand, in the extreme case of high demand observed in the eighth scenario, the results obtained by the multi-objective approach are in line with the second configuration, i.e. that of reducing the quantity of CO2 emissions. On both sides and between the two situations, for the different intermediate scenarios (3 to 7), the method gave an intermediate solution for both objectives.

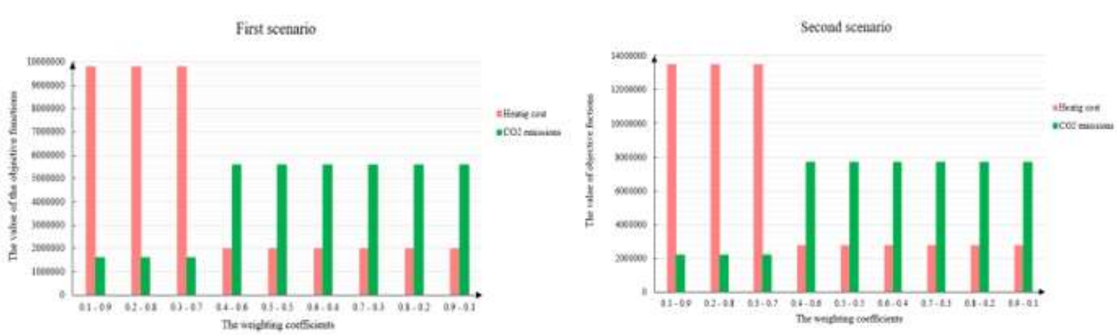
The weighting coefficients impact:

To justify the areas of choice of best pairs of multi-objective cost results with respect to the environment, the following table presents the tests of the sets of weights used in our case study by the LP metric method.

Table 3: The Weighting Coefficients Pairs.

The pair	**1st pair**	**2nd pair**	**3rd pair**	**4th pair**
The value	0.1 - 0.9	0.2 - 0.8	0.3 - 0.7	0.4 - 0.6
The pair	**5th pair**	**6th pair**	**7th pair**	**8th pair**
The value	0.5 - 0.5	0.6 - 0.4	0.7 - 0.3	0.8 - 0.2

The results obtained are presented in the following figure:



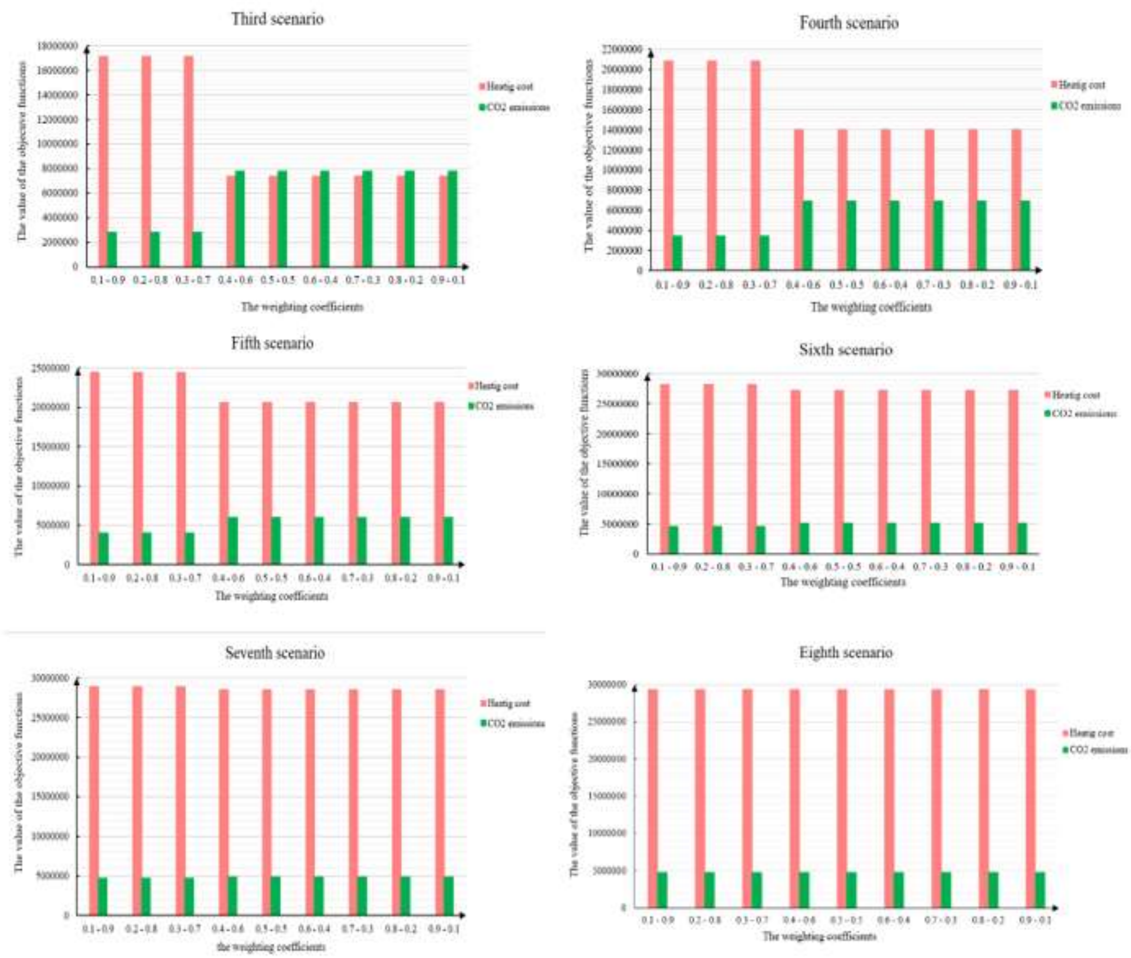


Fig.3: the impact of the weighting coefficients on the LP metric method optimisation.

In more detail, when the demand is low, such as the cases of the first and second scenario, the changes of the weighting coefficients force the variability and the mutation of the studied system towards the environmental dominance. Thus, for the first three couples, the method focuses on the second objective (minimization of CO2 emissions) and for the other couples, the method focuses on the first objective (minimization of the heating cost).

As for the intermediate scenarios, those presented in the range of values three to seven, respectively the first three pairs favor the dominance of CO2 emission reduction. The remaining pairs of this interval, on the other hand, offer more visibility with respect to the concrete consideration of multi-objectives.

Finally, concerning the eighth scenario and due to the threshold of CO2 emission, in the case of high demand, the studied system forces the results of the model to choose the broiler breeding by electric heating. Indeed, to produce as much quantity of chickens to satisfy the demand, the low rate of carbon dioxide emission due to electric heating justified this decision choice despite the variability of the weighting coefficients.

VII. CONCLUSION

The broiler production value chain has an important part in the human nutrition as a source of protein. Unfortunately, its production in good functional conditions requires high energy consumption due to heating at a temperature of 28 degrees which often leads to increased CO2 emissions. To reduce this negative impact on the environment, we present in this paper a bi-objective approach oriented towards cost minimization and CO2 emission reduction. To quantify these conflicting objectives, we developed two models optimizing cost and CO2 emissions independently, by adopting the mathematical approach of operational research based on mathematical integer programming, we justified and optimized the choice of energy source between electric and gas on a case of broiler breeding in the city of Tlemcen in Algeria. To justify the bi-objective considerations, weights by the LP metric method have been tested on a set of variable demands on a farm network of medium instance. Note that our contribution provided and brought satisfactory results for the studied system, we plan in the next studies to add other variants at the modelling and at the resolution approach.

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