Acta Technologica Agriculturae 2
Nitra, Slovaca Universitas Agriculturae Nitriae, 2025, pp. 97–104

# EVALUATING THE EFFICIENCY OF ENERGY CONSUMPTION IN DAIRY CATTLE BREEDING UNIT USING STATISTICAL AND ANFIS METHODS

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Evaluating the input and output process of energy in agricultural systems is one of the ways to determine the level of sustainability in these systems. For this reason, the purpose of this study was to investigate and predict the amount of input and output energies and also related indicators in cattle breeding. The information needed to conduct this study was collected by referring to Pars Company and extracting the recorded information regarding the amount of consumed inputs and the value of produced products. Also, part of the information was extracted from the financial reports presented by the company and the reports published in the annual meetings of the shareholders. In addition, the information is related to the financial period from 2011 to 2020. Based on the available data, the value of input and output energies, energy indices were calculated. Also, adaptive network-based fuzzy inference system (ANFIS) was used to predict performance and output energy. According to the results of data analysis, the average energy required for raising cattle during a one-year period was 52,604.52 MJ·cow$^{-1}$. Also, produced milk, produced manure, and born calf were considered as the output energies. The energy equivalent of produced milk during a year was 56,821.39 MJ·cow$^{-1}$. After examining different models of ANFIS, the best ANFIS model with the input membership function of trimf was selected and the $R^2$ and *MAPE* values of 0.98 and 0.42 were obtained, respectively.

**Keywords:** modelling; calf; input, milk; manure

The impressive population growth requires sufficient food production from limited resources. For example, the demand for dairy products will increase up to 80% in 50 years by 2050 (Kraatz, 2012). The development of the agricultural industry, due to population growth and limited resources, the optimal use and increase in the productivity of production factors are very important. In addition to responding to the growing needs of agricultural products, the agricultural sector can perform its role efficiently in the way of the country's economic growth (Erdal et al., 2007). Currently, energy plays a key role in the economic and social development of all countries, and the importance and value of this element in development increases every day. Hence, if we can properly manage energy consumption, overall productivity in all production fields can be improved (Ozkan et al., 2004).

Milk and its related products are among the best sources of protein and calcium, and considerable investment is made in all countries in the field of their production, trade, and optimal consumption. According to the reports of the World Food and Agriculture Organisation (FAO) in 2009, the amount of milk production in the world was estimated 699 million tons. Iran's milk production was equal to 1.1% of the total world production and 3% of the total production in Asia. In 2009, Iran ranked as the 18$^{th}$ largest producer of milk in the world (FAO, 2010). According to the data from the statistical plan of the country's industrial cattle farms in 2018, the total number of industrial cattle farms was 26,983 with a capacity of 3,670,796 heads. Of these, 16,836 industrial cattle farms with a total capacity of 2,380,187 heads were related to dairy cattle breeding, and 10,147 industrial cattle farms with a total capacity of 1,290,609 heads were related to cattle and calf breeding activities (Irandataportal, 2014). Today, more than 83% of the world's milk production is related to the cattle industry. Despite the small share of industrial cattle farms in Iran, the share of milk production of industrial cattle farms is more than 62% of the total cows' farms.

Agriculture is one of the most important economic sectors of the country, attention to which can lead to the prosperity of other sectors, such as industry and services, to the point where it can be said that economic growth is not possible without the growth of agriculture. One of the very useful methods in analysing and evaluating the sustainability of agriculture is the use of energy as a calculation tool (Erdal et al., 2007). The flow of energy in agriculture is divided into two parts: input and output energy.

Input energies are:

1. Direct energy: Resources such as fossil fuels, human power, and electricity, which are used directly in the product production process, are called direct energy (Martinho, 2021).

2. Indirect energy: Indirect energy use refers to the energy embodied in all the input factors that are to be consumed in a production system such as chemical fertilisers, herbicides, pesticides, insecticides, seeds, and agricultural machines. It has been estimated that fuel and fertilisers, in particular nitrogen, amount more than 60% of all the consumables embodied energy (Hernanz et al., 2014). Since these entities are produced outside the farm and then enter the agricultural ecosystem, they are called indirect energy.
3. Renewable energy: This type of energy comes from the repetitive or continuous process that is happening naturally in the world around us. The examples of this type of energy can be considered solar energy, wind energy, geothermal energy, sea tides, etc (Kaygusuz, 2001).
4. Non-renewable energy: Non-renewable energy sources are those resources that can be produced after many years. Static resources that can only be extracted by humans and until then are stored as resources. Nuclear energy and fossil fuels such as oil, natural gas, and coal are among these sources (Salvador, 2005).

Output energy: The energy equivalent of the produced product (milk, meat, seeds, straw) is called output energy (Eskandari et al., 2011). Energy ratio, energy efficiency, specific energy, and net added energy are among the criteria for checking the flow of energy during crop production operations (Hernanz et al., 2014).

Amid et al. (2016) conducted energy efficiency modelling with the help of perceptron artificial network approach in 70 broiler chicken production units in Ardabil. They found that the total amount of equivalent energy input and output in broiler chicken production in the region is about 154.28 and 59.56 MJ per 1000 birds, respectively. The best structure for artificial neural network modelling of the energy consumption of broiler production was estimated as 5–14–52 with 5 inputs, a hidden layer with 14 neurons, and an output layer with two output parameters. In another study conducted by Soltanali et al. (2015) on 44 industrial cattle breeding units, the information collected through a questionnaire was analysed by Cobb-Douglas function. The results showed that two inputs of animal feed and fossil fuels account for a high share of energy consumption with 82% and 13%, respectively. The total energy input, energy efficiency, specific energy, added energy, and energy efficiency for each head were 52,592.81 MJ, 0.25 $L \cdot MJ^{-1}$, 7.40 $MJ \cdot L^{-1}$, 27,743.08 MJ and 0.47, respectively. In an energetic study which was conducted in German dairy farms, the results showed that the food ration and animal feed constitute the major part of the input energy. The energy efficiency of milk production was between 3 and 3.6 $kg \cdot MJ^{-1}$ (Kraatz, 2012).

Considering the limited natural resources on the one hand and the adverse effects of inappropriate use of different energy sources on human health and the environment on the other hand, it seems necessary to examine different energy models in the agricultural sector. The novelty of this project is to find an optimum model for the energy balance in dairy breeding units to manage the energy cycle in the best way. The goals of this research are:

1. Checking and extracting the energy indicators in the dairy cattle breeding unit.
2. Providing a suitable model of ANFIS for predicting the energy.

## Material and Methods

The purpose of this research was to investigate the flow of energy in dairy cattle breeding units and to provide new methods to improve their performance. Then, the data related to the consumption of inputs during one year was recorded in the Moghan Agriculture Company. The data were collected using the methods of calculating energy indices, data envelopment analysis, neural network and its integration with fuzzy logic. In this research, basic information about input energy and energy indicators were analysed using SPSS 21 software, and MATLAB 2016a software was used to predict the flow of energy consumption. ParsAbad Mughan city is located in the northwest of Iran and the north of Ardabil province between 39° 8′ to 39° 42′ north latitude and 47° 52′ to 48° 6′ east longitude. The required information was collected by referring to Pars agriculture company and extracting the recorded information regarding the values of consumed inputs and the amount of produced products. Also, part of the information was extracted from the financial reports presented by the company and the reports published in the annual meetings of the shareholders. In addition, the information is related to the period from the beginning of financial year 2011 to the end of 2020. The statistical population was a cattle breeding unit with 2000 cattle.

The inputs used for breeding dairy cattle were feed for livestock, fuel used for feeding and harvesting equipment and tools, machines and equipment including tractors, feeder mixers, milking equipment, ventilation and spraying systems, electricity, and human power. The outputs of the studied system were produced milk, manure, and calves. The energy equivalent of the inputs and outputs of the production system was considered based on the coefficients and equivalents in past researches, and in this way, the energy consumed in the milk production process was calculated. The coefficients of inputs and outputs are presented in Table 1.

The equivalent energy of used fuel expressed in $MJ \cdot L^{-1}$ was calculated according to Eq. (1) (Kitani et al., 1999; Chamsing et al., 2006).

$$E_f = F_c \times E_{c,f} \tag{1}$$

where: $E_f$ – equivalent energy of consumed fuel (MJ); $F_c$ – amount of fuel consumed (L or $m^3$); $E_{c,f}$ – energy content of a unit of fuel ($MJ \cdot L^{-1}$)

Equation (2) was used to compute the equivalent energy of used implements.

$$E_m = W_m \times E_{c,m} \tag{2}$$

where: $E_m$ – energy equivalent of implement (MJ); $W_m$ – implement weight (kg); $E_{c,m}$ – energy content of one kilogram of implement ($MJ \cdot kg^{-1}$)

**Table 1** The energy equivalent of inputs and outputs

| Inputs | Unit | Energy equivalent (MJ·unit$^{-1}$) | Reference |
|---|---|---|---|
| **Human power** | h | 1.96 | Kitani et al. (1999) |
| **Tractors and other propelled machines** | kg·a | 9–10 | Kitani et al. (1999) |
| **Stationery machines** | kg·a | 8–10 | Kitani et al. (1999) |
| **Agricultural implements** | kg·a | 6–8 | Kitani et al. (1999) |
| **Steel** | kg | 62.7 | Chauhan et al. (2006) |
| **Galvanised iron** | kg | 38 | Lawson (1996) |
| **Polyethylene** | kg | 46.3 | Lawson (1996) |
| **Electromotor** | kg | 64.8 | Chauhan et al. (2006) |
| **Gasoline** | L | 47.8 | Kitani et al. (1999) |
| **Petrol** | L | 46.3 | Kitani et al. (1999) |
| **Oil** | L | 36.7 | Kitani et al. (1999) |
| **Gas** | m$^3$ | 49.5 | Kitani et al. (1999) |
| **Electricity** | kWh | 11.93 | Ozkan et al. (2004) |
| **Straw** | kg | 2.77 | Frorip et al. (2012) |
| **Concentrate** | kg | 6.3 | Lawson (1996) |
| **Silage** | kg | 2.2 | Wells (2001) |
| **Alfalfa** | kg | 1.5 | Wells (2001) |
| **Outputs** | | | |
| **Milk** | kg | 7.14 | Coley et al. (1998) |
| **Manure** | kg | 0.3 | Loghmanpour Zarini et al. (2019) |
| **Calve** | kg | 6.5 | Frorip et al. (2012) |

The energy equivalent of electricity was computed using Eq. (3) and Table 1.

$$E_{elec} = E_{el} \times E_{c,\,el} \tag{3}$$

where: $E_{elec}$ – energy equivalent to consumed electricity (MJ); $E_{el}$ – amount of consumed electricity (kWh); $E_{c,\,el}$ – energy content of a unit of electricity (MJ·kWh$^{-1}$)

The energy equivalent of the consumed feed was calculated using Eq. 4:

$$E_N = W_N \times E_{c,\,N} \tag{4}$$

where: $E_N$ – animal feed equivalent energy (MJ); $W_N$ – amount of feed consumed (kg); $E_{c,\,N}$ – energy content of one kilogram of feed (MJ·kg$^{-1}$)

The energy consumption of manpower was calculated from Eq. (5) (Unakitan and Aydin, 2018).

$$E_{la} = N_{la} \times \mathrm{h} \times E_{c,\,la} \tag{5}$$

where: $E_{la}$ – energy equivalent of human power (MJ); $N_{la}$ – number of labours (person); $h$ – working hour (h); $E_{c,\,la}$ – energy content per person (MJ·person$^{-1}$)

## Output energy

Considering that milk, manure, and born calf are considered as outputs of the studied unit, it is possible to calculate their energy equivalent by considering the values presented in Table 1 and the weight of each of the produced products.

$$E_{ou} = W_{ou} \times E_{c,\,ou} \tag{6}$$

where: $E_{ou}$ – the energy equivalent of the outputs produced in dairy farming, including milk, manure, calf (MJ); $W_{ou}$ – production amount of each output (kg); $E_{c,\,ou}$ – energy content of one unit of each product (MJ·kg$^{-1}$)

## Energy indicators

Based on the input and output energy equivalents obtained from Eq. (1) to Eq. (6), the energy ratio (ER), energy productivity (EP), and net energy generation (NEG) in both grain and biological conditions are calculated from the following equations (Chamsing et al., 2006).

$$ER = \frac{EO}{EI} \tag{7}$$

where: $EO$ – output energy (MJ·cow$^{-1}$); $EI$ – input energy (MJ·cow$^{-1}$)

$$EP = \frac{PO}{EI} \quad (8)$$

where: $PO$ – milk output (kg·cow$^{-1}$)

$$NEG = EO \text{ (Mj·cow}^{-1}) - EI \text{ (Mj·cow}^{-1}) \quad (9)$$

### ANFIS modelling approach

The basis of ANFIS is based on the set of input/output data of a fuzzy inference system (FIS). This system is based on the rules of a combination of three parts: the membership functions of input and output variable (fuzzification), rule evaluation, defuzzification (transfer truth values into output) (Krueger et al., 2011). Jang and Sun (1997) used the linguistic power of fuzzy systems and neural network training and presented a system called adaptive neuro fuzzy inference system (ANFIS). Often, ANFIS systems use a Takagi-Sugno-Kang (TSK) fuzzy system as a progressive network structure (Moinfar and Shahgholi, 2019). For simplicity, we assume that our fuzzy system has two inputs of x and y, and its output is z. Now, the rules are as follows:

$$\text{Rule1: if } x \text{ is } A_1 \text{ and } y \text{ is } B_1 \text{ then } f_1 = P_1x + q_1y + r_1 \quad (10)$$

$$\text{Rule2: if } x \text{ is } A_2 \text{ and } y \text{ is } B_2 \text{ then } f_2 = P_2x + q_2y + r_2 \quad (11)$$

If we use the average method for de-fuzzification (transforming the final output of the system into a classical number), the output will be as follows:

$$f = \frac{w_1f_1 + w_2f_2}{w_1 + w_2} = \bar{w}_1f_1 + \bar{w}_2f_2 \quad \text{st} \quad \bar{w}_1 = \frac{w_2}{w_1 + w_2} \qquad \bar{w}_2 = \frac{w_1}{w_1 + w_2} \quad (12)$$

The equivalent structure of ANFIS, which consists of five layers, will be as follows.

The first layer – in this layer, the degree of membership of the input nodes to different fuzzy intervals is determined by the membership function:

$$O_{1,i} = \mu A_i(x), \text{ for } i = 1, 2\ldots\ldots O_{1,i} = \mu B_i(y), \text{ for } i = 3, 4 \quad (13)$$

The Gaussian membership function $\mu A_i\,(x)$ is expressed as follows:

$$A_i(x) = \exp\left[-\left(\frac{x - c_i}{a_i}\right)^2\right] \quad (14)$$

where: $a_i$ and $c_i$ – the set of parameters (initial parameters); $x$ – the input of the $i^{th}$ node

The second layer – each node in this layer calculates the degree of activity of a rule:

$$O_{2,i} = w_i = \mu A_i\,(x) \times \mu B_i\,(y),\; i = 1, 2 \quad (15)$$

The third layer – the output of this layer is normalised of the previous layer:

$$O_{3,i} = \bar{w}_i = \frac{w_i}{w_1 + w_2},\; i = 1, 2 \quad (16)$$

The fourth layer or result nodes – in this layer, the output of each node is equal to:

$$O_{4,i} = \bar{w}_if_i = \bar{w}_iP_ix + q_iy + r_i \quad (17)$$

The fifth layer or output nodes – in this layer, each node calculates the final output value as follows (the number of nodes equals the number of outputs):

$$O_{5,i} = \sum_i \bar{w}_if_i = \frac{\sum_i w_if_i}{\sum_i w_i} \quad (18)$$

A hybrid training method is one of the most important training methods for ANFIS. In this method, the error back propagation method is used for training in the first layer and the least squares estimation method is used in the fourth layer of the system (Jang and Sun, 1997). In this research, models were created based on the parameters mentioned in the previous section in MATLAB 2016a software and in the Fuzzy Logic Toolbox section.

Due to the fact that in this study, the number of inputs was less than 5, there was no need to cluster the input data. In the second stage, all ANFIS modellings with triangular membership function (trimf), bell-shaped (gbellmf) and Gaussian (gaussmf), as well as linear and constant output membership function were implemented using MATLAB 2016a software. Also, hybrid and backpropagation optimization methods were used, and the results of different models were evaluated in terms of statistical parameters.

In order to check the ability and capability of the proposed models in this study, the statistical indicators of correlation coefficient ($R^2$) and mean absolute percentage error ($MAPE$) were used (Eqs 10 and 11).

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(t_i - Z_i)}{\sqrt{\sum_{i=1}^{n} t_i^2}} \quad (19)$$

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left(\frac{|(t_i - Z_i)|}{Z_i}\right) \times 100 \quad (20)$$

## Results and Discussion

### Input and output energies

According to the results, the average energy required for breeding cattle during a one-year period was 52604.52 MJ per cow. According to Fig. 1, animal feed and fuel have allocated the largest share of 82% and 13% of input energy, respectively. In order to manage animal feed consumption, it is possible to increase feed efficiency by properly adjusting the ration, especially micronutrients and supplements. Considering that the feed is used in the form of mesh in the studied unit, it is suggested to use pelleted feed instead of this method, which has more economic and energetic efficiency.

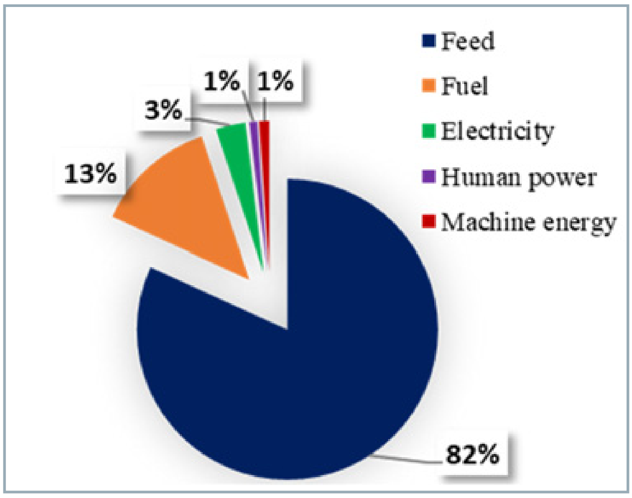


**Fig. 1** The share of the main parameters on annual input energy

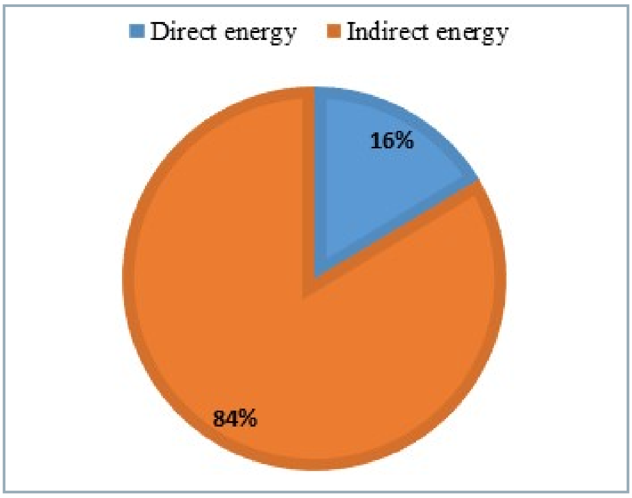


**Fig. 2** The share of direct and indirect energies of total input energy

Logmanpour et al. (2016) found that in dairy farms, the amount of input energy for raising cows and producing milk per head of livestock was 56,563.42 MJ·cow$^{-1}$. It was estimated that animal feed with an average energy of 43,611.97 MJ for each head of livestock consumed 77% of the total energy. The amount of output energy was 58,277.02 MJ per head of livestock. Sefeedpari et al. (2014) in dairy farms of Tehran province found that the amount of energy input per cow was 53,102 MJ and the amount of output energy was 58,315 MJ·cow$^{-1}$.

The input energy in dairy cows can be classified into two groups: direct energy (fuel energy and electricity) and indirect energy (food, manpower, etc.). The amount of each of these energies and the contribution of each of them is presented in Fig. 2. It was found that 8,596.93 MJ (14%) of input energy was direct energy, and 44,700.59 MJ (86%) was indirect energy. Also, input energy can be divided into two categories: renewable energy like labour force and non-renewable energy such as fuel, food, and machinery. Results indicated that only 1% of the total energy consumed in Pars Agriculture Company was provided from renewable sources, and 99% was related to natural resources (non-renewable). This proved that the non-renewable energy sources like fossil fuels and machines provided a major part of input energy, while renewable energies play a minor role in the production process. Therefore, an excessive consumption of non-renewable energy resources in agricultural production systems affects the ecosystem in the long term, and this can cause the instability of production systems.

Milk produced, manure, and born calf were considered as the main resources of output energy of a cattle breeding unit. The equivalent energy of milk produced during a period of one year was 56,821.39 MJ per head of livestock (Table 2).

Energy indices were calculated for the milk production process, and the results are presented in Table 3.

### ANFIS modelling results

Considering that the studied system has three different outputs, including milk, manure, and calf, each of the outputs is modelled separately with ANFIS. Then, the performance of each of the presented models is evaluated using the coefficient of determination $R^2$ and the average absolute error, and the best model is selected (Table 4). In addition, various membership functions, including trimf, gbellmf, and gaussmf, have been used in order to model the flow of energy.

**Table 2** The total output energy and its resources quantity

| **Parameters** | **Value (MJ·cow$^{-1}$)** | **Percentage (%)** |
|---|---|---|
| **Produced milk** | 56,821.39 | 92 |
| **Manure** | 2,927.17 | 5 |
| **Born calf** | 2,253.53 | 2 |
| **Total output energy** | 62,002.09 | 100 |

**Table 3** Energy indices for evaluation dairy cattle breeding

| **Energy indices** | **Value** |
|---|---|
| **Energy ratio** | 1.17 |
| **Energy efficiency** | 0.57 |
| **Net energy generation** | 9,397.57 |

**Table 4** ANFIS model information and its evaluation parameters for predicting the energy output of the milk

| ANFIS information | Input membership function | | Number of membership functions | | Optimisation method | $R^2$ | *MAPE* |
|---|---|---|---|---|---|---|---|
| **Number of nodes: 92**<br>**Number of linear parameters: 32**<br>**Number of nonlinear parameters: 30**<br>**Total number of parameters: 62**<br>**Number of training data pairs: 84**<br>**Number of fuzzy rules: 32** | input | outpot | input | epoch | | | |
| | gaussmf | linear | 2-2-2-2 | 10 | hybrid | 0.95 | 0.91 |
| | gbellmf | linear | 2-2-2-2 | 10 | hybrid | 0.97 | 0.6 |
| | trimf | linear | 2-2-2-2 | 10 | hybrid | 0.99 | 0.32 |

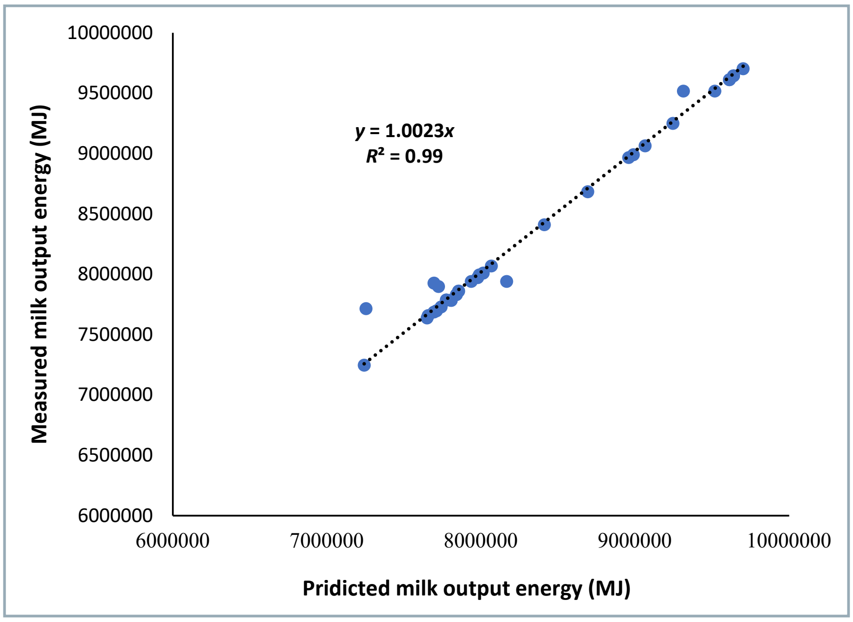


**Fig. 3** Relationship between the predicted and measured output energy of milk

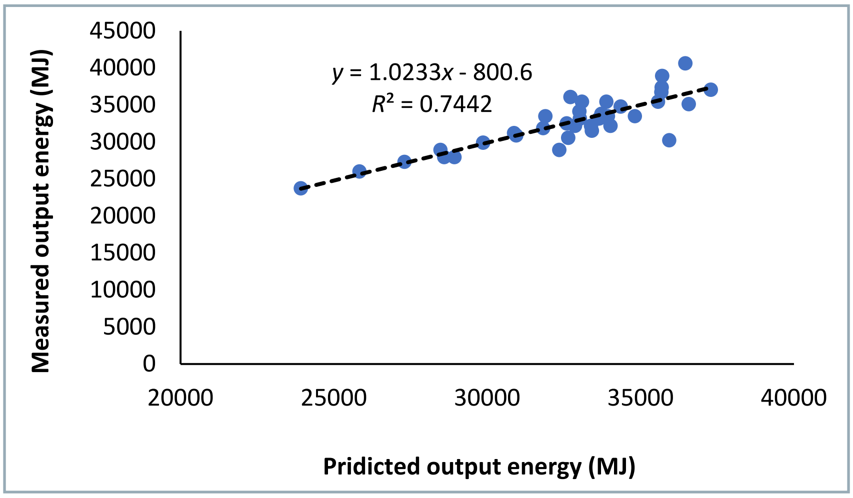


**Fig. 4** Relationship between the predicted and measured output energy of born calf

In the first case, the produced milk is considered as the output. The statistical indices related to the best ANFIS models were evaluated with different membership functions. A high $R^2$ value of 0.98 and the minimum *MAPE* value of 0.32 were obtained using the trimf function, respectively. Table 4 presents the information related to the best ANFIS model proposed for the production value, such as the number of nodes, linear and non-linear parameters, and the number of fuzzy rules.

Figure 3 shows the relationship of predicted and measured values of output milk using different settings in Table 4. It should be noted that during the milk production process, some of the produced milk is destroyed due to having an inappropriate microbial agent. This problem can be prevented by using new methods. Then, system efficiency can be increased significantly due to milk share in the output.

In the second scenario, the born calf is considered as the output of the model. The statistical indices related to the best ANFIS model with the triangular input membership function $R^2$ and *MAPE* values of 0.74 and 0.42 were obtained, respectively. Figure 4 shows the relationship between the measured and predicted values using the ANFIS models under different conditions. The reason for the low $R^2$ in the calf can be due to the fact that considering the energy of the total feed received by the dairy cow for the growth of the calf is not true because the major part of this energy in the dairy cow is used for the production of milk and the metabolic energy of the cow.

Finally, the produced manure energy is considered as the output of the model. The model with triangle membership function was found as an optimum model for prediction, and the resulting values of $R^2$ and *MAPE*

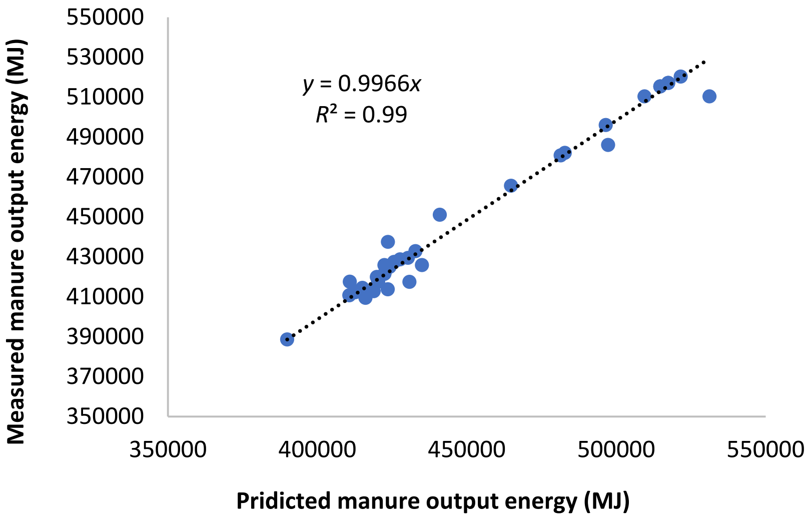


**Fig. 5** Relationship between the predicted and measured output energy of produced manure

were 0.98 and 0.42, respectively. Figure 5 shows the relationship between the measured and predicted values of manure energy using the ANFIS models. It was found that the amount of manure produced in the studied unit was significant. The manure is stored using traditional methods and then transferred to the surrounding fields as fertiliser. Efficiency will be increased if the produced manure can be used as a biogas source for supplying the energy used during the breeding process of dairy cows (Sefeedpari et al., 2014; Kovačić et al., 2019).

## Conclusion

1. It was found that the average equivalent energy required for raising dairy cow during one year was 52,604.52 MJ·cow$^{-1}$. Produced milk, produced manure, and born calf were considered as the output of a cattle breeding unit. The equivalent energy of output products was 62,002.09 MJ·cow$^{-1}$ during a year; hence, energy ratio was 1.17. Feed and fuel have allocated the largest share of input energy of 82% and 13%, respectively.
2. Only 1% of the total energy consumed in the cattle breeding unit was provided from renewable sources, and the rest was related to non-renewable energy sources. This indicates that fossil fuels, machines, etc. include a major share of input energy from non-renewable energy sources, and renewable energies play a minor role in dairy cow breeding units.
3. The $R^2$ and *MAPE* values of 0.98 and 0.42 were obtained, respectively, using the optimum ANFIS model with the input membership function trimf. Due to its high accuracy, multi-layer ANFIS is an applicable tool for the prediction and management of the energy process in large-scale agricultural production systems for sustainable production.

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