

# Chapter 16

## Energy Decomposition Model Using Takagi-Sugeno Neuro Fuzzy

Yusak Tanoto and Felix Pasila

**Abstract** Decomposition analysis is useful method to determine significant factors contribute towards the development of energy consumption. This paper presents factors decomposition of electricity consumption in Indonesia's household sector using artificial intelligent method. The proposed artificial intelligent technique used in this study is the Neuro Fuzzy Takagi-Sugeno (NFTS) network, which is worked under multiple input multiple output condition. By tuning the appropriate Gaussian parameters, which are mean and variance, and two Takagi-Sugeno weight, the changes in electricity consumption that is decomposed into production effect, structural effect, and efficiency effect, has revealed. Compared to the common method, the performance of NFTS network for both constant and current price variables is quite satisfied, given the error generated in the network ranges between 0.003 and 2.09 %, which is quite low and acceptable.

**Keywords** Takagi-Sugeno Neuro Fuzzy · Factors decomposition · Household · Electricity consumption

### 16.1 Introduction

Energy factors decomposition is a useful method to determine significant factors contribute towards the development of energy consumption over the observed period. Several studies have reported the factors decomposition of the electricity energy using the well-known decomposition technique, Logarithmic Mean Divisia Index, or hereafter called LMDI. The technique is currently applied in many decomposition study. LMDI is used to reveal the electricity development of the Brazilian residential sector [1]. Decomposition of four term energy intensity of Hong Kong residential sector is studied using LMDI method [2]. Additive-LMDI

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with emphasis on both current and constant price based is used to observe Indonesian household electricity decomposition [3].

In this paper, a novel approach in obtaining the energy factors decomposition is used. One of the objective is to decompose production, structure, and efficiency effect using alternative technique that are reliable, accurate and without having to understand mathematical model of the method. Therefore, artificial intelligent based method is used to obtain those decomposition factors of electricity utilization. The proposed Neuro Fuzzy Takagi-Sugeno network is applied to the Indonesia's electricity energy in the household sector. The data used in this study are the same with that applied in the previous study with LMDI method, in order to compare results obtained by the proposed method with that demonstrated by Additive-LMDI.

This paper is organized as follows; the methodology consists of NFTS network architecture and the data is presented in the following section. Subsequently, followed by results and discussion section. Finally, conclusion of the work is presented in the last section.

### 16.2 Methodology

The proposed NFTS network model in which applied in this study is shown in Fig. 16.1 below. The method is already proven as one of artificial intelligence approximator for modelling and control [4]. The proposed network consists of 5 set

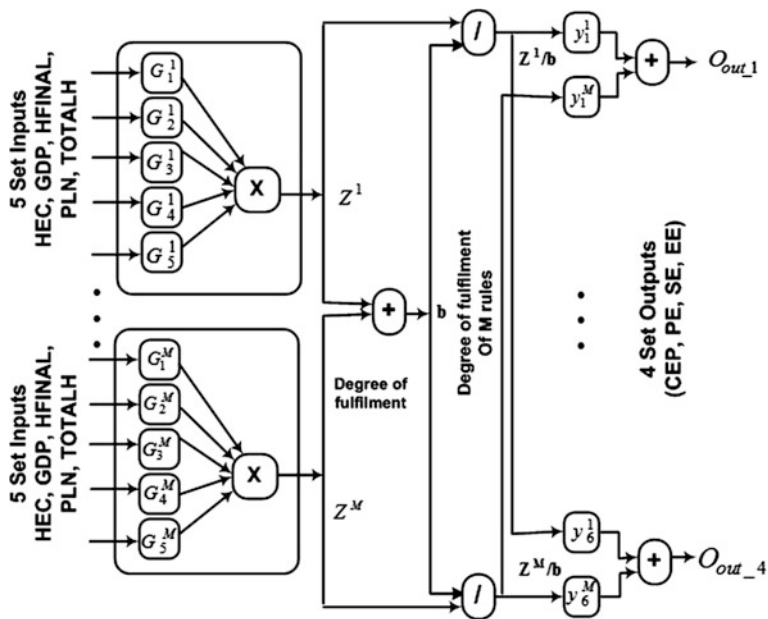


Fig. 16.1 NFTS network model for the case study with 5 set inputs and 4 set outputs

inputs, i.e. household electricity consumption (HEC), Gross Domestic Product (GDP), household final consumption expenditure (HFINAL), PLN’s household customer (PLN), and total number of household (TOTALH), and 4 set outputs, i.e. changes in electricity consumption (CEC), production effect (PE), structure effect (SE), and efficiency effect (EE).

The proposed model of NFTS as shown in Fig. 16.1 is based on TS-fuzzy rule, product inference, and weighted average defuzzification. All nodes in the Gaussian layer calculate the degree of membership of the fundamental input values (HEC, GDP, HFINAL, PLN and TOTALH) in the antecedent fuzzy parts. The division and the summation nodes in the degree of fulfillment parts, join to make the normalized units of the corresponding rules, which after multiplication with the corresponding TS parts, is used as input to the last summation part at the four outputs.

The outputs of NTFS, which being crisp, are directly well-approximated with the related outputs (CEP, PE, SE and EE). If all the parameters for NFTS network are selected, then the NFTS can approximate any nonlinear model based on given related data between 5 inputs and 4 outputs. The parameters used in the NFTS network, such as Gaussian and TS parameters can be optimized through Levenberg-Marquardt Algorithm (LMA) learning procedure. In this study, we apply the same data in accordance to previous study made with the Additive-LMDI method. The five set inputs for the data are taken from year 2000 to 2010. Also, the GDP and household final consumption expenditure are expressed either in current price and constant price 2000. All data are shown in Tables 16.1 and 16.2, respectively.

**Table 16.1** Data required for conducting Indonesian household electricity decomposition (current price)

Year	Household electricity consumption (MWh) [5]	GDP (million Rupiah) [6]	Household final consumption expenditure (million Rupiah) [6]	PLN’s household customer [5]	Total number of household [5]
2000	30,538,269	1,389,769,900	856,798,300	26,796,675	52,008,300
2001	33,318,312	1,646,322,000	1,039,655,000	27,905,482	53,560,200
2002	33,978,744	1,821,833,400	1,231,964,500	28,903,325	55,041,000
2003	35,697,122	2,013,674,600	1,372,078,000	29,997,554	55,623,000
2004	38,579,255	2,295,826,200	1,532,888,300	31,095,970	58,253,000
2005	41,181,839	2,774,281,100	1,785,596,400	32,174,924	59,927,000
2006	43,748,580	3,339,216,800	2,092,655,700	33,118,262	55,942,000
2007	47,321,668	3,950,893,200	2,510,503,800	34,684,540	57,006,400
2008	50,182,040	4,948,688,400	2,999,956,900	36,025,071	57,716,100
2009	54,944,089	5,606,203,400	3,290,995,900	37,099,830	58,421,900
2010	59,823,487	6,436,270,800	3,643,425,000	39,324,520	61,363,100

**Table 16.2** GDP and household final consumption expenditure (constant price 2000)

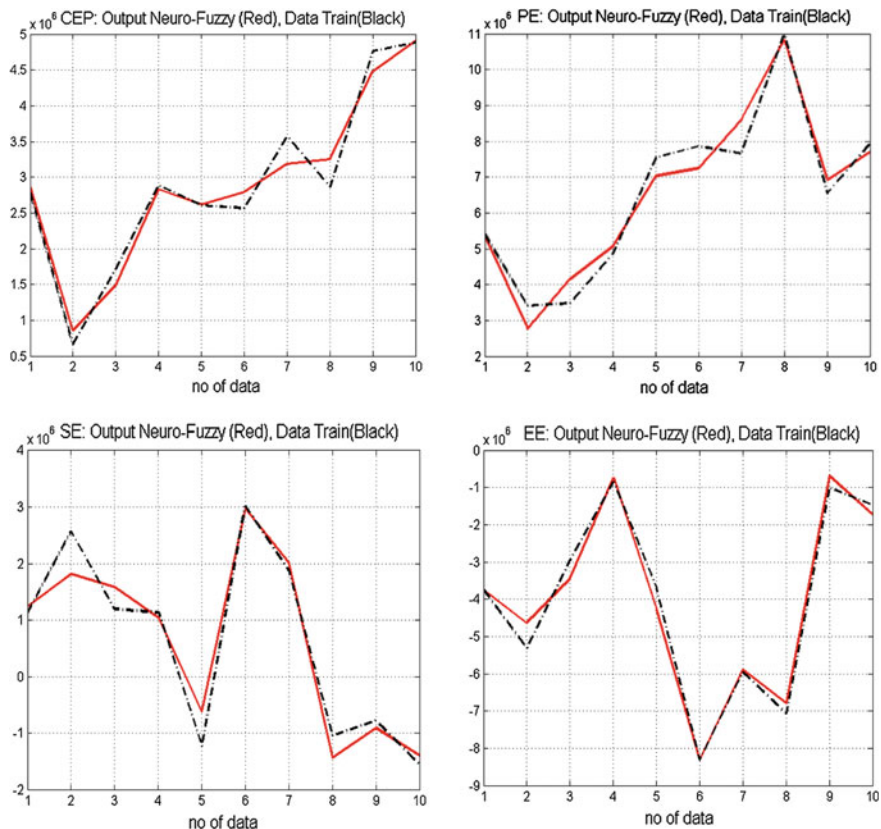
Year	GDP (million Rupiah) [6]	Household final consumption expenditure (million Rupiah) [6]
2000	1,389,769,900	856,798,300
2001	1,440,405,700	886,736,000
2002	1,505,216,400	920,749,600
2003	1,577,171,300	956,593,400
2004	1,656,516,800	1,004,109,000
2005	1,750,815,200	1,043,805,100
2006	1,847,126,700	1,076,928,100
2007	1,964,327,300	1,130,847,100
2008	2,082,456,100	1,191,190,800
2009	2,178,850,400	1,249,070,100
2010	2,313,838,000	1,308,272,800

### 16.3 Results and Discussion

The changes in Indonesia's household electricity consumption during year 2000–2010 according to the current price and constant price are shown in Fig. 16.2 and Table 16.3, respectively.

In the case of current price data, changes in electricity consumption is driven by 224.66 % production effect, 21.47 % structural effect, and -137.67 % efficiency effect. Meanwhile, in the case of constant price based data, the changes in electricity consumption is affected by percentage of production effect, percentage of structure effect, and percentage efficiency effect.

Table 16.4 gives the comparison between results obtained by NFTS network model and by Additive-LMDI. In this regards, the results achieved by the LMDI method are taken as the baseline. The performance of NFTS network is quite satisfied. The error generated in the network is in the range between 0.003 and 2.09 %, which is quite low and acceptable. For instance, the largest error with 2.09 % means according to the NFT network, the 2000–2010 changes in electricity consumption is affected by 5,593,004.21 MWh consumption contributed by structure effect. This value is only a difference of 119,592 MWh compared to LMDI. The least difference is obtained for the case of current price based data, particularly for structural effect, provided a difference of only 210 MWh between NFTS and LMDI.



**Fig. 16.2** NFTS output versus data trained: CEC (first upper), PE (second upper), SE (lower), EE (lowest)

**Table 16.3** NFTS output: 2000–2010 (constant price 2000)

Year	Changes in electricity consumption ( $\Delta E_{tot}$ in MWh)	Production effect ( $\Delta E_{act}$ in MWh)	Structural effect ( $\Delta E_{str}$ in MWh)	Efficiency effect ( $\Delta E_{int}$ in MWh)
2000–2001	2,782,762.14	1,169,160.93	308,740.49	1,307,567.53
2001–2002	953,571.05	1,349,106.83	11,641.39	−968,277.02
2002–2003	1,669,749.11	1,647,257.37	616,649.55	−554,780.20
2003–2004	2,486,164.26	2,029,069.96	−26,214.54	973,591.61
2004–2005	2,622,593.22	2,160,692.25	−691,953.41	1,178,029.05
2005–2006	2,591,168.35	2,369,558.62	3,150,399.62	−2,775,936.45
2006–2007	3,299,091.29	2,637,449.12	787,838.87	36,358.10
2007–2008	3,273,223.22	2,711,828.61	357,713.70	−166,207.44
2008–2009	4,694,108.54	2,498,907.49	1,201,014.41	1,333,001.74
2009–2010	4,771,860.99	3,460,405.03	−122,825.88	1,168,861.27
2000–2010	29,144,292.18	22,033,436.22	5,593,004.21	1,532,208.20
		75.60 %	19.19 %	5.25 %

**Table 16.4** Result comparison between NFTS model and Additive-LMDI

Tools (Type of data)	CEC	PE	SE	EE
LMDI (current)	29,285,218.00	65,685,080.79	6,280,558.64	-40,413,112.57
NFTS (current)	29,244,768.02 (Error: 0.14 %)	65,701,890.94 (Error: 0.03 %)	6,280,768.654 (Error: 0.003 %)	-40,261,612.49 (Error: 0.375 %)
LMDI (constant)	29,285,218.00	22,021,829.43	5,712,597.09	1,550,791.46
NFTS (constant)	29,144,292.18 (Error: 0.48 %)	22,033,436.22 (Error: 0.05 %)	5,593,004.21 (Error: 2.09 %)	1,532,208.20 (Error: 1.19 %)

## 16.4 Conclusion

This paper presents the utilization of Artificial Intelligence tool based to model factors decomposition of Indonesia household electricity consumption. Based on the testing to the provided data, changes of household electricity consumption can be modelled satisfactory by the NFTS network along with three types of effect that affecting the changes in electricity consumption. Despite of the limited set of data, the multi input-multi output NFTS can performed well and results achieved in term of error are very low, especially for the case of current price based data.

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