

# UWL REPOSITORY repository.uwl.ac.uk

Constructing a smart framework for supplying the biogas energy in green buildings using an integration of response surface methodology, artificial intelligence and petri net modelling

Shahsavar, Mohammad M., Akrami, Mehran, Gheibi, Mohammad, Kavianpour, Babak, Fathollahi-Fard, Amir M. and Behzadian, Kourosh ORCID: https://orcid.org/0000-0002-1459-8408 (2021) Constructing a smart framework for supplying the biogas energy in green buildings using an integration of response surface methodology, artificial intelligence and petri net modelling. Energy Conversion and Management, 248. p. 114794. ISSN 0196-8904

http://dx.doi.org/10.1016/j.enconman.2021.114794

This is the Accepted Version of the final output.

UWL repository link: https://repository.uwl.ac.uk/id/eprint/8304/

Alternative formats: If you require this document in an alternative format, please contact: <u>open.research@uwl.ac.uk</u>

Copyright: Creative Commons: Attribution-Noncommercial-No Derivative Works 4.0

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

**Take down policy**: If you believe that this document breaches copyright, please contact us at <u>open.research@uwl.ac.uk</u> providing details, and we will remove access to the work immediately and investigate your claim.

1	Constructing a novel smart framework for supplying biogas energy in green
2	buildings using an integration of response surface methodology, artificial
3	intelligence and petri net modelling
4	Mohammad M. Shahsavar <sup>1</sup> , Mehran Akrami <sup>2</sup> , Mohammad Gheibi <sup>2,3</sup> , Babak
5	Kavianpour <sup>3,4</sup> , Kourosh Behzadian <sup>5</sup> , Amir M. Fathollahi-Fard <sup>6*</sup>
6	<sup>1</sup> Department of Civil Engineering, Sajad University of Technology, Mashhad, Iran
7	<sup>2</sup> Department of Civil Engineering, Ferdowsi University of Mashhad, Mashhad, Iran
8	<sup>3</sup> Zistpardazesharia Knowledge Based Company, Mashhad, Iran
9	<sup>4</sup> Department of Chemical Engineering, School of Chemical and Petroleum Engineering, Shiraz
10	University, Shiraz, Iran
11	<sup>5</sup> Department of Civil Engineering, University of West London, London, UK
12	<sup>6</sup> Department of Electrical Engineering, École de Technologie Supérieure, University of Québec,

#### 15 Abstract

Montréal, Canada

16 Nowadays energy crisis is considered an essential active issue for future urbanization in 17 megacities. While the rate of population growth increases, the volume of municipal solid waste production increases significantly. This highlights the need of Sustainable Development Goals 18 19 (SDGs) for both developed and developing countries. This paper introduces a novel smart 20 framework for supplying biogas energy to study waste management and energy supply in green 21 buildings. This framework integrates the Response Surface Methodology (RSM), Artificial 22 Intelligence (AI), and Petri net modeling. Firstly, the particular biogas generation setup is invented 23 for food waste digestion by integrating Sequencing Batch Reactors (SBR) sludge and Clostridial 24 microorganisms. Before experimental practices, for evaluation of waste characterizations, the 25 quartering and coning method is utilized. In the experimental practices, different variables including Sludge/Waste, Inoculum (Clostridiales/Waste), pH, Temperature and, time, are 26 27 appraised in the lab-scale setup. Also, in the experimental section for measuring the variables through biogas production procedure, three protocols containing EPA-821-R-01-015, Organic 28 29 Matter and alkalinity evaluation by American Public Health Association (APHA, 2017) and 30 Einhorn Saccharometer technique are utilized. The optimum conditions are appraised based on 31 Central Composition Design (CCD) using RSM. Artificial intelligence techniques including the

32 Random Tree (RT), Random Forest (RF), Artificial Neural Network (ANN) and, Adaptive-

- Network-based Fuzzy Inference System (ANFIS) are employed. Plus, for creating the optimum
   condition, a dynamic controlling system Petri Net modeling is used.
- 35 The outcomes of present investigation have illustrated that the optimum conditions for Sludge/food
- 36 Waste (S/W), *Clostridiales*/ food Waste (C/W), pH, Temperature (T) and Retention time (t) as
- 37 effective parameters are equal to 163 mg/g, 54 mg/g, 7, 30 °C and 55 days, respectively. Likewise,
- 38 the analysis of variance (ANOVA) assessment demonstrated that the most effective parameters
- 39 are S/W and T with high amount of F-value and low amount of P-value. Plus, between all machine
- 40 learning methods, ANFIS with 0.99 correlation coefficient had the best accuracy for Accumulated
- 41 Biogas Production (ABP) based on effective factors.
- 42 Sludge and Clostridial based bio-engine are compared with together asper biogas/methane
- 43 generation and fluctuation of Total Organic Carbon (TOC), Chemical Oxygen Demand (COD)
- 44 and total alkaline are appraised. The outcomes have demonstrated that efficiency of sludge-based
- 45 system is two times more than Clostridial based reactors, because of available nutrient and active
- 46 microorganisms. Finally, Circular Economy (CE) scrutinizing have proved that with application
- 47 of this method in a green building, all electrical energy/heat demands can be supplied by 381 kwh
- 48 (3051 MJ) in the case study (In one residential unit). Also, the remained digested food waste with
- 49 310 mg/L COD is valuable for gardening activities in green buildings.
- 50 Finally, with the outcomes of present study, some different scientific issues such as clean energy
- 51 supplying in green buildings, smart sustainable biogas production control system, Integrated Solid
- 52 Waste Management (ISWM), CE and SDGs in green buildings are tackled as a novel framework
- 53 in smart and sustainable cities.
- 54 Keywords: Biogas, Food Waste, Sludge, Clostridial Microorganisms, Response Surface
   55 Methodology, Artificial Intelligence, Petri Net Modelling;

# 56 **1. Introduction**

- 57 One of the main concerns in Green Building Concepts (GBC) [1], Sustainable Development Goals 58 (SDGs) [2] and Clean Technologies Theory (CTT) [3] is related to stable energy supplying in 59 short, middle and long terms [4]. When energy demand is increased in different megacities of 60 developing countries based on population accumulation [5], consumerism [6], cultural diversion
- 61 [7] and global warming effects [8] which is continued every year. Plus, waste generation,
- 62 especially biological wastes in developing countries, is augmented as per life style changing [9]
- 63 and developing urbanization in some countries such as Iran [10], India [11] and China [12]. Energy
- 64 crisis and biological waste generation problem are noteworthy challenges when they are seen
- 65 separately, but, in a holistic view of GBC, they can be considered as an opportunity for biogas
- 66 production for implementation of CTT in future lifestyle of developing countries [13].
- 67 Biogas generation from biological wastes is assumed as a green method for Integrated Solid Waste
- 68 Management (ISWM) during anaerobic digestion in household reactors [14, 15]. The scheme of

- 69 Circular Economy (CE) in biogas generation from biological waste and biochemical reaction are
- 70 illustrated in Figs. 1 [16-18] and 2 [19-21], respectively. According to Fig. 1, with CE approach
- 71 the threats of waste generation can be converted to opportunities for energy demand crisis and
- 72 fertilizer providing in green building's plants from digested wastes [22]. Whereas, as per Fig. 2, it
- 73 is clear that biogas generation is done in four stages containing hydrolysis, acidogenesis,
- 74 acetogenesis, and methanogenesis [23].
- 75





Fig. 1. The schematic plan of biogas generation cycle [16-18].





Fig. 2. The schematic plan of biochemical reactions [19-21].

81 Cavaignac et al. (2021) have presented a novel concept for operation of biogas reactors with 82 considering technical, economic and environmental aspects. In the mentioned study, main issue 83 was related to amine scrubbing role in biogas generation enhancing. Plus, by application of Life Cycle Assessment (LCA) method, emission of CO<sub>2</sub> was predicted with high accuracy [24]. Also, 84 85 Miranda et al. (2021) have evaluated green technologies for energy supplying in some countries including Brazil, Russia, India, China, and South Africa (BRICS). For the mentioned goal, 86 87 Methodi Ordinatio methodology with concentration on sustainability indices was used [25]. Plus, 88 Niu et al. (2021) have designed a biogas system for rural usages energy providing in China. In this 89 study, environmental and social benefits have been scrutinized by monetization method. Likewise, 90 the performance of partially competitive strategy is discussed for medium- and large-scale biogas projects (MLBPs) [26]. Abanades et al. (2021) have presented a framework for biogas generation 91 92 in the globe based on critical review concept [27]. Lomazov et al. (2021) have optimized biogas 93 energy production plants with application of fuzzy and genetic algorithm techniques [28]. Stürmer 94 et al. (2021) have compared the biogas production based on agricultural wastes in different regions. 95 The declared research has assessed legal framework and regional structures on biogas production 96 [29]. Jung et al. (2021) and Akbulut et al. (2021) have designed local biogas system in large-scale with considering syngas system energy supplying and energy planning in Malatya, respectively 97 [30, 31]. Brémond et al. (2021) have presented a novel framework for improvements of solid 98 99 digestion process in Continuously Stirred Tank Reactors (CSTRs) with agricultural waste feeding. 100 In the declared study, some different strategies are assessed for enhancing the efficiency of biogas 101 production [32]. Naquash et al. (2021) have presented some outcomes for production of Liquefied 102 Natural Gas through solidification of CO<sub>2</sub> through biogas procedure. Likewise, in the mentioned 103 investigation, all simulations are done in Aspen Hysys® v11 platform [33]. Moreover, Zhang et 104 al. (2021) have designed food-waste-to-energy system as decentralized energy supplying 105 approach. The researchers have concentrated on organic matter loading and temperature effects on 106 biogas production efficiency. Also, with application of Sankey diagram in energy flow, the 107 performance of anaerobic digestion and Combined Heat and Power (CHP) are scrutinized [34]. 108 Wu et al. (2021) have scheduled the biogas-solar-wind as Integrated Energy Systems (IESs) in a 109 case study. In the mentioned study, for programming energy usages multi-objective optimization 110 (MOO) are utilized [35]. Su et al. (2021) have presented a novel system for thermal collecting of 111 bio-methane production with application of photovoltaic facilities. In the avowed research, reducing the fossil fuel consumption are proposed as cost function [36]. 112

113 As the reviewed investigations, application of Artificial Intelligence (AI) and Response Surface

114 Methodology (RSM) for biogas generation in green building energy supplying is so rare as a

research gap and this research wants to present a novel smart model for bio-energy contributing.

116 The present study aims to:

- Inventing biogas setup for household energy applications based on biological wastes in
   green buildings with combination of *Clostridiales*, wastewater treatment plant's sludge and
   food wastes digesting activities.
- Optimizing the effective parameters on biogas production in green buildings by Central
   Composition Design (CCD)-RSM technique.
- Creating smart controlling model for operating system by Random Tree (RT), Random
   Forest (RF), Artificial Neural Network (ANN) and Adaptive-Network-based Fuzzy
   Inference System (ANFIS) soft computations.
- 125 Presenting controlling model in green buildings as per Petri net system.
- 126 In the present study, with application of CCD-RSM technique, the optimum conditions are
- 127 determined and likewise, the number of experimental runs are reduced. On the other words, by
- 128 CCD-RSM method plus enhancing the performance of biogas production process, the
- 129 experimental costs are decreased. In the followings, the AI computations evaluate the behavior
- 130 of bio-system performance for controlling possible reactor's problems in the especial situations
- 131 with prediction the future manners. Finally, with comparison of the outcomes of AI and CCD-
- 132 RSM, the effective method for controlling and prediction of biogas production are suggested
- 133 as the scientific fact.
- The rest of this paper is organized as follows: Section 2 provides the materials and methods including the framework of this research, used materials, instrumentation, lab-scale setup, microbiological methods, optimization, prediction and controlling models. Section 3 presents the test results and provides the discussion on the results. Finally, a summary of this research with findings and recommendations, is concluded in Section 4.
- 139

# 140 **2. Materials and methods**

# 141 **2.1.Case study**

142 The present research is done in a residential complex with fifteen household units which is 143 illustrated as per Fig. 3. Also, monthly electrical demand (Fig. 4) of each unit is demonstrated in 144 Fig. 4 according to PVSystem simulations software [37]. Plus, approximate analysis of food wastes

145 which is appraised based on quartering and coning method [38] is summarized in Table 1.



Fig. 3. Location of Mashhad, Iran.





Fig. 4. The pattern of electrical energy consumption in the case study in Mashhad, Iran.

Waste type	Percentage	Moisture (%)	
Paper	21	8	
Glass	9	2	
Food waste	40	82	
Plastic waste	27	12	
Cloth waste	3	15	

Table 1. Approximate specification of residential wastes as per quartering and coning method in
 present research.

158

#### 159 **2.2.Research roadmap**

In this study, research roadmap is divided to four sections such as experimental efforts,
 optimization and statistical evaluations, predictive models and controlling algorithm as a
 Decision Support System (DSS) which are demonstrated in Fig. 5.

163 According to Fig. 5, in the first step, the energy demands of the case study is computed by 164 simulation and application of some different data banks. By applying this section, the value of energy demand is determined in different months. Then, with quartering and coning method, 165 the quality and quantity of available solid wastes are measured as the first section of second 166 167 stage. Plus, in the second section the lab scale setup is designed and built and then in the last section of this stage, the experimental efforts are started. For design of experiments, CCD-168 169 RSM method is employed as sensitive analysis, optimization and regression prediction 170 equations. After, optimizing the mentioned experiments by CCD-RSM, the suggested 171 optimum conditions are compared by real test's amounts until reaching to desirable precision. 172 If the CCD-RSM values are not fit to real experiments, the CCD-RSM should be redesigned. 173 In the next stage, by the CCD-RSM outcomes, Petri Net modelling are done for creating the 174 concept of smart operation system of biogas generation process with focusing on approved 175 optimum conditions. In the fifth stage of present research, the RF, RT, ANN and ANFIS 176 computations are utilized for smart forecasting microorganism's behavior through the biogas 177 production procedure. Finally, after assessment of biogas energy supplying performance in this 178 study, a conceptual model is designed for implementation of SDGs. CE and ISWM in the research. 179



182 Fig. 5. The research roadmap of present study (CCD-RSM: Central Composition Design-Response Surface

183 Methodology, AI: Artificial Intelligence, RT: Random Tree, RF: Random Forest, ANN: Artificial Neural Network

and ANFIS: Adaptive-Network-based Fuzzy Inference System, CE: Circular Economy, SDGs: Sustainable
 Development Goals and ISWM: Integrated Solid Waste Management)

#### 186 **2.3.Materials and instrumentation**

All reagents and materials for experimental practices and sampling are shown in Table 2.
Likewise, sampling is done three times with quartering and coning method, initial and final
gas generation tests. Whereas, all applied instruments are utilized for sampling, gas
measurement and effective parameters determinations are mentioned in Table 3.

191

Table 2. Crucial materials and regents for present study.

Compounds	Conditions	Company
NaOH	Molecular weight is equal to 40 gr mol <sup>-1</sup>	Sigma Aldrich, USA
Secondary sludge sedimentation as an inoculum	This sludge have been provided from secondary clarifier tank in Sequencing Batch Reactor (SBR)	From Al-Teymour wastewater treatment plant in Mashhad City
Silicone glue	Silicon, nanopowder, <100 nm particle size (TEM), ≥98% trace metals basis with 28.09 gr mol <sup>-1</sup> molecular weight	Sigma Aldrich, USA
N <sub>2</sub> gas	Nitrogen, ≥ 99.998% with 28.01 gr mol <sup>-1</sup> molecular weight	Sigma Aldrich, USA

	70% purity and with	
HNO <sub>3</sub>	63.01 gr mol <sup>-1</sup>	Sigma Aldrich, USA
	molecular weight	
Mixed food waste	It is obtained after	From Case study in
Wixed 100d waste	one day	Mashhad City
Clostridiales	Liquid sample	Iranian Genetic Bank (IGB)

Table 3. Functional equipment in present study.

Instrument	Conditions/model/description	Company
Vacuum flask	With glass hose connector	VWR® International Co.
Vacuum pump	Suction Capacity 550 to 15000 m <sup>3</sup> h <sup>-1</sup>	PPI pumps Co.
Lab scale storage	Borosilicate Glass	BOROSIL Technologies Co.
One-liter glass batch-mode digester	High pressure and temperature mode	Nunc Lab-Tek Co.
pH meter	Thin. Professional.	Hanna pH meter Co.
Total Organic Carbon meter	multi EA® 5100 for Micro- Elemental Analysis	Analytik Jena Co.
Autoclave	Vertical floor-standing autoclaves (top-loading) from 40 to 150 liters chamber volume	Systec. V-Series Co.
Bain-marie	Stainless Steel Bain Marie (Brand:SSFW), 220V	Mindiamart Co.

Oven	Drying oven 125 basic dry (5 - 250 centigrade degree )	IKA Co.
Electrical control circuit	Micro Pragma	Schneider Electric Co.
Chemical Oxygen Demand meter	Fits 16mm or 13mm Hach COD vials, Test N Tube vials or TNTplus™ vials	Hach Co.
Submersible pump	SKU: ECO-185	Lab society Co.
Temperature sensor	Sensor Net Connect Temperature Monitoring	Plug & Track Co.
Pneumatic connections	UNIFLEX™ BASIC model	BROEN-LAB Co.
Electro thermal elements	Steel with 403 grade and temperature threshold is equal to 400 °C	Iran element Co.
Gas storage bag	High pressure and temperature mode	Nunc Lab-Tek Co.
Heat water tank	High pressure and temperature mode	Nunc Lab-Tek Co.
Einhorn's saccharometer	The carbon dioxide created in the fermenting process would rise to the top of the closed tube and force the level of liquid down.	VWR Co.
20 cc syringe	Standard plastic mode	Samen Co.

# **2.4.Lab-scale setup and experimental methodology**

- 195 The schematic plan of biogas lab scale setup including mechanical devices, chemical sensors
- and equipment and structural tools are depicted in Fig. 6. Also, the algorithm of experimental
- 197 methods in each run is illustrated in Fig. 7.





- 201
- 202

Fig. 7. The algorithm of experimental methods in present study [39-41].

#### 203 **2.5.CCD-RSM model**

204 In this study, CCD-RSM statistical model is used in Design Expert 7.0.0 software which it determines sensitive analysis, optimum conditions and mathematical regression based 205 206 predictive model for energy supplying in green buildings. Also, in the Design of Experiments 207 (DOE), value of alpha is set in 1.2 amount [42]. The specifications of DOE for each effective 208 parameter in this study is demonstrated in Table 4. In this research Accumulated Biogas 209 (methane) Production (ABP) is assumed as a cost function (response) in ml unit. Both sludge 210 and Inoculum play role as bio-engine for degradation of food waste in biogas generation cycle. 211 But, in present investigation, the character of each one is separated for comparison of 212 wastewater treatment plant's bacteria and *Clostridiales* gas generation abilities. The key 213 parameters for experimentation are selected as per literature review evaluations in different 214 investigations [29-31, 39-41].

Table 4. The variables and values used for biogas process optimization in CCD.

Variables	ariables Syr			Code	Coded factors level		
	Unit	I	-1.2 (Low)	+1	0	-1	1.2 (High)
Sludge/Waste	mg/gr	S/W	90	100	150	200	210
Inoculum (Clostridiales/Wast e)	mg/gr	C/W	6	10	30	50	54
pН		рН	5.2	6	7	8	8.2
Temperature	°C	Т	6.5	25	35	45	48.5
Time	day	t	6	10	30	50	54

After determination of optimum conditions, for creating smart controlling models Petri Net [43] concept is utilized. In the declared model, each adjustable factor and conditional values are put in place and transition functions, correspondingly. The algorithm of Petri Net modelling design is shown in Fig. 8.



- 220
- 221

Fig. 8. Schematic plan of Petri Net modelling in present study.

# 222 **2.6.AI techniques**

In the present study, for creating the predictive model as smart controlling systems, some different machine learning computations such as ANN [44], ANFIS [45], RT [46] and RF [47] are used. For implementation of the mentioned algorithm MATLAB 2013 b and WEKA software are performed which is described in Table 5.

Method	Software	Conditions
ANN	WEKA 3.9	Multilayer perceptron and percentage split is set on 90%
RT	WEKA 3.9	Cross-validation folds are set on 30
RF	WEKA 3.9 and MATLAB 2018b <sup>®</sup>	Percentage split is set on 80%
ANFIS	MATLAB 2018b®	Sugeno, membership functions are three Gaussian type 2, optim method and number of epochs are selected equal to hybrid and 70, correspondingly.

#### 229 **3. Results and discussions**

#### 230 **3.1.Optimization and experiments**

231 The outcomes of experimental efforts as per analysis based on CCD-RSM technique are 232 summarized in Table S.1. Plus, the fitness of Linear, 2FI, Quadratic and Cubic distributions have 233 illustrated that the R-Squared and Predicted R-Squared of quadratic function is more acceptable in 234 comparison of other ones (Table 6). According to Table 6, quadratic model with 0.92 and 0.64 R-235 Squared and Predicted R-Squared can achieve the best outcomes in curve fitting aspect (Equation 236 1). In mathematical viewpoint, quadratic model could satisfy ABP (ml) according to effective parameters containing S/W, C/W, pH, T and t. But, for prediction ABP, the created statistical 237 238 model with 0.62 Predicted R-Squared cannot meet forecasting expectations. Thus, for estimations 239 of ABP, application of AI can be useful as an online soft monitoring system in detail of DSS.

240

Table 6. The results of mathematical models in CCD-RSM.

Std. Dev.	R- Squared	Adjusted R- Squared	Predicted R- Squared	PRESS	
1518.185	0.20	0.119179	0.0187	1.26E+08	
1647.652	0.28	-0.03745	0.18523	1.96E+08	
1125.946	0.92	0.515523	0.64	1.26E+08	Suggested
867.7422	0.91	0.712247	-0.79628	2.3E+08	Aliased
	<b>Std.</b> <b>Dev.</b> 1518.185 1647.652 1125.946 867.7422	Std.R-Dev.Squared1518.1850.201647.6520.281125.9460.92867.74220.91	Std. Dev.         R- Squared         Adjusted R- Squared           1518.185         0.20         0.119179           1647.652         0.28         -0.03745           1125.946         0.92         0.515523           867.7422         0.91         0.712247	Std.         R-         Adjusted         Predicted           Dev.         Squared         R-         R-           1518.185         0.20         0.119179         0.0187           1647.652         0.28         -0.03745         0.18523           1125.946         0.92         0.515523         0.64           867.7422         0.91         0.712247         -0.79628	Std. Dev.         R- Squared         Adjusted R- Squared         Predicted R- Squared         PRESS           1518.185         0.20         0.119179         0.0187         1.26E+08           1647.652         0.28         -0.03745         0.18523         1.96E+08           1125.946         0.92         0.515523         0.64         1.26E+08           867.7422         0.91         0.712247         -0.79628         2.3E+08

Table 5. The AI computation specifications in present research.

242	ABP = -46061.41463 + 126.90239 * S/W + 85.91509 * C/W + 9832.81639 * pH + 237.44436 * T-
243	4.22495 * t-0.034750 * S/W * C/W-3.26625 * S/W * pH+0.026214 * S/W * T-0.10325 * S/W *
244	t-12.65625 * C/W * pH-0.23429 * C/W * T+1.04234 * C/W * t-0.81786 * pH * T-1.35625 * pH
245	*t+0.035000*T*t-0.29929 * (S/W) <sup>2</sup> -0.10317 * (C/W) <sup>2</sup> -612.44931*(pH) <sup>2</sup> -3.62682*(T) <sup>2</sup> +0.12339
246	$(t)^{2}$

260

241

The outputs of analysis of variance (ANOVA) evaluations and sensitive analysis is demonstrated 248 249 in Table 7 and Fig. 9, respectively. With considering to Table 7, The P-value of model and its lack of fit are computed equal to less than 0.0001 (significant) and 0.1415 (not significant) respectively, 250 251 which it conveys high level of validity in achieved statistical model. Also, according to Table 7, the P-Value of both S/W and T factors are less than 0.0001. Therefore, S/W and T have the most 252 significant effect on ABP in comparison other ones. Likewise, the F-value of S/W with 89.73 253 254 amount is more than T parameter (with 11.09) and it determines that S/W is the most important 255 parameter between all effective factors on ABP. Whereas, the least significant parameter is related 256 to t with 0.28 and 1.19 P-value and F-value correspondingly. The sensitive analysis of dual 257 effective parameters vs ABP is illustrated in Fig. 9. As per this Fig., the most slope variations are 258 related to S/W and T factors which illustrate the influences of them on ABP in comparison of other 259 ones.

Source	Sum of Squares	df	Mean Square	F Value	p-value (Prob > F)	
Model	91455700	20	4572785	3.60	< 0.0001	significant
A-S/W	10235044	1	10235044	89.73	< 0.0001	
B-C/W	1611124	1	1611124	1.27	0.26	
С-рН	3700598	1	3700598	2.91	0.09	
D-T	9741058	1	9741058	11.09	< 0.0001	
E-t	1517780	1	1517780	1.19	0.28	
AB	38642	1	38642	0.03	0.86	
AC	853471.1	1	853471.1	0.67	0.41	
AD	16836.13	1	16836.13	0.01	0.90	
AE	341138	1	341138	0.27	0.60	
BC	2050313	1	2050313	1.61	0.21	
BD	215168	1	215168	0.17	0.68	
BE	5562780	1	5562780	4.38	0.04	
CD	6555.125	1	6555.125	0.005	0.94	

Table 7. The results of ANOVA evaluation in CCD-RSM.

CE	23544.5	1	23544.5	0.018	0.89	
DE	4802	1	4802	0.003	0.95	
A^2	2832988	1	2832988	2.23	0.14	
B^2	8618.599	1	8618.599	0.006	0.93	
C^2	1898166	1	1898166	1.49	0.23	
D^2	6243064	1	6243064	4.92	0.03	
E^2	12327.59	1	12327.59	0.009	0.92	
Residual	36764876	29	1267754			
Lack of Fit	32146334	22	1461197	2.21	0.14	not significant
Pure Error	4618542	7	659791.6			-
Cor Total	1.28E+08	49				



















269



(e)







(f)

8.20

7.60

C: pH

274	Fig. 9. The sensitive analysis of effective parameters in CCD-RSM.
275	The normal plot of residuals is demonstrated in Fig. S.1 which shows distribution of ABP's
276	results in neighborhood of normal diagram. So, the results of experimental activities follow
277	normal statistical distributions in different runs. The five suggested optimum conditions based
278	on CCD-RSM computations are summarized in Table 8. According to declared Table,
279	optimum values of S/W, C/W, pH, T and t are equal to 163 mg/g, 54 mg/g, 7, 30 °C and 55
280	days, respectively. Also, the mentioned suggestions are examined in lab scale setup with three
281	repetitions and 6310.2 ml, 6282.3 ml and 6325.1 are measured as experimental outputs. While,
282	the mean value of predicted ABP with 6259.96 ml has 99.6% accuracy with mean value of
283	experimental results (with 6306.1 ml). Desirability of mathematical prediction outcomes vs
284	variations of S/W and C/W is illustrated in Fig. S.2.

**(J)** 

**(I)** 

285

273

Table 8. The outcomes of optimum conditions in CCD-RSM.

Number	S/W	C/W	рН	Т	t	Predicted ABP (ml)	Experimental outcomes repetition 1- ABP (ml)	Experimental outcomes repetition 2- ABP (ml)	Experimental outcomes repetition 3- ABP (ml)
1	163.1	54	6.97	31.02	55	6261.1			
2	163.69	54	6.98	30.88	52	6260.3			
3	161.76	54	6.99	31	54	6260.2	6310.2	6282.6	6325.5
4	161.45	54	6.93	30.73	51	6259.8			
5	163.08	54	6.92	30.33	53	6258.4			
286									

286

In the followings, experimental outcomes modeled by ANN, RF and RT machine learning algorithms which is shown in Table 9. As per the mentioned soft computing systems, the most accuracy with 0.93 correlation coefficient is related to RT algorithm. Plus, ANN and RF algorithms are in the next places with 0.91 and 0.87 correlation coefficients, respectively. Also, plot matrix of input and output data is demonstrated in Fig. S.3. The computational RT algorithm and RT conceptual model are demonstrated in Equation S.1 and Fig. 10, respectively. With following this tree, ABP of each fabulous condition can be predicted as a soft sensor.

Table 9. The statistical outcomes of ANN, RF and RT algorithms in present research.

Statistical parameters	ANN	RF	RT
Correlation coefficient	0.91	0.87	0.93

<sup>287</sup> **3.2.Smart control systems** 

Mean absolute error	890.97	1070.74	755.6
Root mean squared error	952.41	1207.11	870.98
Relative absolute error	51.58%	58.21%	43.74%
Root relative squared error	49.94%	61.23%	45.67%
Total number of instances	5	10	5



297 298

Fig. 10. The RT conceptual model in present study.

The confusion matrix and parallel coordinates plot of RF algorithm are illustrated in Fig. 11 and S.4, correspondingly. According to Fig. 11, the population of positive predictive value is more than negative predictive value which demonstrates validity of RF computations in this research. Also, the parallel coordinates plot depicts the high level of correct predictions for ABP values as per effective parameters. With focusing on Fig. S.4, staccato lines (as an incorrect prediction) cannot be seen in comparison of allied lines (as a correct estimation).



Fig. 11. The confusion matrix of RF algorithm in present study.

307 Structural of ANFIS model for smart estimation of ABP as per S/W, C/W, pH, T and t with 3 membership functions is depicted in Fig. 12. Also, adaption of training data and FIS outputs is 308 309 declared in Figs. S.5-6 and Table 10 which accent to high level of accuracy in ANFIS 310 computations. Likewise, duo to evaluation of significant degree in each effective parameter for 311 ABP the dual sensitive analysis of ANFIS calculation algorithm is demonstrated in Fig. 13. With regard to Fig.13, it is clear that S/W and T parameters have the most slope variations on 312 the 3D plots and this indicates the high degree of importance of these factors in comparison of 313 314 other parameters.









340 For creating DSS for smart controlling of bio-energy supplying, Petri Net modelling with 341 combination of CCD-RSM optimization are utilized. The invented smart model for bio-energy 342 management is depicted in Fig. 14. In the mentioned smart system, all effective parameters containing S/W, C/W, pH, T and t are set on optimum conditions and they check and modify 343 344 sequentialy until to adjust in appropriate value throught a loop. Also, the mentioned concep first, evaluate S/W and T because of their significant effects on ABP in the parallel lines. Then, in the 345 other series, pH (Souring control plan in the biogas system [48]) and S/W are controlled and 346 347 adjusted. Finally, time of reaction as the least important factor is checked and justified. With 348 application of Petri Net modelling according to Fig. 14, optimum conditions of biogas generation 349 system can be controlled smartly.



350

351

Fig. 14. The Petri Net modelling in present study.

#### 352 **3.3.Green building approach**

353 The results of present research have illustrated that with the role of sludge-based bacteria is more 354 significant than *Clostridiales*. For scrutinizing the mentioned result, the experimental setup is 355 appraised in a run without sludge and in the other one without *Clostridiales*. In each run, all 356 effective parameters are set in optimum conditions, just, sludge and *Clostridiales* injecting are eliminated in determined tests. The output of daily and accumulated biogas/methane vs time 357 358 variations is illustrated as per Fig. 15. According to Fig. 15, with application of sludge (without 359 *Clostridiales*) biogas and methane production are around twice as much as biogas production with 360 Clostridiales (without sludge) during 55-day retention time. One of the main achievements in this 361 research was linked to presenting smart model for dynamic integrated management of sludge and Clostridiales bio-engines in the same time. 362

In the following, the recent investigations approved that 99% of biogas productions including methane and carbon dioxide [49-52]. Also, the nutrients (Nitrogen and phosphor) and active anaerobic microorganisms are provided by injected sludge from secondary clarifier tank in SBR. Thus, in the alone *Clostridiales* bioreactor the efficiency of anaerobic digester is reduced because of less nutrient and active microorganisms' values [53]. Likewise, the variation of TOC, COD and total alkaline of food wastes in both bioreactors (with Clostridiales and sludge) are illustrated in Fig. 16. According to this Fig., the organic matter digestion rate of sludge-based system is more than Clostridiales based bioreactor which is related to biodegradation ability of sludge-based

- 371 microorganisms [54]. The alkalinity increasing in both reactors can be related to protein and amino
- acid biodegradation in the sequential reactions (Equation 3) [55]. While, in sludge-based system,
- 373 rate of biodegradation is more than alone *Clostridiales* system and therefore, the amounts of total
- alkaline is increased in the declared system.

375

Equation 3



376  $NH_3 + H_2O + CO_2 \otimes NH_4^+ + HCO_3^-$ 

377378

(a)



Fig. 15. Daily and accumulated biogas/methane production in (a) sludge based system and
(b) Clostridiales based system.



(a)





As a result, it is clear that integration of SBR's sludge and Clostridiales can enhance the efficiency of bio-reactor in this study. Also, as can be seen in Table S.1, the integrated bioreactor has the acceptable efficiency in the low retention time and temperature which is affected by dual bioengine activities in the same time [56]. In the last part of this research, pattern of energy production according to Circular Economy [57], Industry Ecology (IE) [58], Integrated Solid Waste Management (ISWM) [59] and Sustainable Development Goals (SDGs) [60] is illustrated in Fig.

385

386

397 17. Whereas, the digested food waste is biogas generation procedure can be useful as a fertilizer

- 398 [61,62]. As per Fig. 17, the electrical energy generation of biogas system in present research can
- 399 supply all energy demand based on Fig. 4. Also, the produced energy can be utilized for heat
- 400 demand with 3051 MJ in 55-day (One operating duration) as a bio-energy supplying in green
- 401 buildings. Finally, the digested organic materials with 310 mg/L COD value is appropriate for
- 402 green environmental supporting in residential complex in the case study. Also, with considering
- 403 to Fig. 4, the energy demand of case study is ranged 250 350 kwh/month and based on the
- 404 achievements of present study, the available biogas energy is around 175 kwh/month (By 40%
- 405 efficiency [63]). Therefore, around 50% of energy demand in the case study can be provided by
- 406 biogas production in the present study.



407

Fig. 17. The conceptual model of CE, ISWM and SDGs for implementation of green buildings in
 present investigation.

410

# 411 **4.** Conclusion

Food wastes have high level of variety in forming compositions containing proteins, fatty acids,carbohydrates, vitamins and other organic matters that they can product considerable

414 biogas/methane through anaerobic digestion process. The declared technique is so beneficial for

- 415 waste management and bio-energy supplying in the same time as a novel approach in green
- 416 buildings. One of the main concerns about application of biological process in energy supplying
- 417 is related to complexity of operation. Therefore, combination of smart controlling soft systems
- 418 with biodegradation techniques can cover the weakness of bio-systems.
- 419 The main experimental, numerical and simulation practices in present research including:
- 420 Preparing lab-scale setup for anaerobic digestion of food wastes with SBR's sludge and
   421 *Clostridiales* microorganisms.
- 422 Optimizing and sensitive analyzing effective parameters by CCD-RSM technique.
- 423 Implementation of smart system with four soft computing techniques containing RT, RF,
  424 ANN and ANFIS.
- 425 Creating dynamic control system for adjusting effective parameters with Petri Net
  426 modelling.
- 427 Assessment of SBR's sludge and *Clostridiales* on food waste anaerobic digestion in
   428 separated reactors.
- 429 Presenting conceptual model as a CE platform for green buildings.
- 430 In the following, as per all experimental and computational efforts the main outcomes are listed431 below.
- Optimum values of S/W, C/W, pH, T and t are computed equal to 163 mg/g, 54 mg/g, 7,
  30 °C and 55 days, respectively based on CCD-RSM optimization.
- The most significand effective factors on ABP/Methane production are S/W and T with
   less than 0.0001 P-value according to ANOVA calculations.
- The correlation coefficient of RT, RF, ANN and ANFIS computations are equal to 0.93,
  0.87, 0.91 and 0.99 values. Therefore, ANFIS model has the best precision for ABP forecasting in DSS.
- In the Petri Net model, controlling S/W and T is prioritized in comparison of other
   parameters because of their P-value and F-value amounts.
- The efficiency of SBR's sludge is more than *Clostridiales* based bioreactor because of nutrient availability and activity of microorganisms. In the same conditions, methane production of sludge-based bioreactor 42% is more than other one.
- With performing bio-energy supplying 381 kwh (3051 MJ) can be obtained that is enough
   for electrical energy demand or heat energy consumption.
- 446

# 447 **References:**

448 1- Mojtahedi, M., Fathollahi-Fard, A.M., Tavakkoli-Moghaddam, R. and Newton, S., 2021.
449 Sustainable vehicle routing problem for coordinated solid waste management. Journal of
450 Industrial Information Integration, 23, p.100220.

- 2- Eftekhari, M., Gheibi, M., Azizi-Toupkanloo, H., Hossein-Abadi, Z., Khraisheh, M.,
  Fathollahi-Fard, A.M. and Tian, G., 2021. Statistical optimization, soft computing prediction,
  mechanistic and empirical evaluation for fundamental appraisal of copper, lead and malachite
  green adsorption. Journal of Industrial Information Integration, 23, p.100219.
- 455 3- Ali, S.M., Paul, S.K., Chowdhury, P., Agarwal, R., Fathollahi-Fard, A.M., Jabbour, C.J.C. and
  456 Luthra, S., 2021. Modelling of supply chain disruption analytics using an integrated approach:
  457 An emerging economy example. Expert Systems with Applications, 173, p.114690.
- 4- Theophilus, O., Dulebenets, M.A., Pasha, J., Lau, Y.Y., Fathollahi-Fard, A.M. and Mazaheri,
  A., 2021. Truck scheduling optimization at a cold-chain cross-docking terminal with product
  perishability considerations. Computers & Industrial Engineering, 156, p.107240.
- Fasha, J., Dulebenets, M.A., Fathollahi-Fard, A.M., Tian, G., Lau, Y.Y., Singh, P. and Liang,
  B., 2021. An integrated optimization method for tactical-level planning in liner shipping with
  heterogeneous ship fleet and environmental considerations. Advanced Engineering
  Informatics, 48, p.101299.
- 465 6- Zhang, C., Fathollahi-Fard, A.M., Li, J., Tian, G. and Zhang, T., 2021. Disassembly Sequence
  466 Planning for Intelligent Manufacturing Using Social Engineering Optimizer. Symmetry, 13(4),
  467 p.663.
- 468 7- Islam, M.R., Ali, S.M., Fathollahi-Fard, A.M. and Kabir, G., 2021. A novel particle swarm
  469 optimization-based grey model for the prediction of warehouse performance. Journal of
  470 Computational Design and Engineering, 8(2), pp.705-727.
- 471 8- Cai, W., Yang, K., Wu, L., Huang, G., Santoso, A., Ng, B., Wang, G. and Yamagata, T., 2021.
  472 Opposite response of strong and moderate positive Indian Ocean Dipole to global warming.
  473 Nature Climate Change, 11(1), pp.27-32.
- 474 9- Noorollahi, Y., Janalizadeh, H., Yousefi, H. and Jahangir, M.H., 2021. Biofuel for energy self475 sufficiency in agricultural sector of Iran. Sustainable Energy Technologies and Assessments,
  476 44, p.101069.
- 477 10- More, M., Agrawal, C., Sharma, D., Rathore, N. and Samar, K., 2021. Development of Pellet
  478 Machine for Utilization of Biogas Slurry. In Advances in Engineering Design (pp. 509-519).
  479 Springer, Singapore.
- 480 11-Tagne, R.F.T., Dong, X., Anagho, S.G., Kaiser, S. and Ulgiati, S., 2021. Technologies,
  481 challenges and perspectives of biogas production within an agricultural context. The case of
  482 China and Africa. Environment, Development and Sustainability, pp.1-28.
- 483 12- de Sousa, M.H., da Silva, A.S.F., Correia, R.C., Leite, N.P., Bueno, C.E.G., dos Santos
  484 Pinheiro, R.L., de Santana, J.S., da Silva, J.L., Sales, A.T., de Souza, C.C. and da Silva Aquino,
- 484 Finnello, R.L., de Santana, J.S., da Silva, J.L., Sales, A. I., de Souza, C.C. and da Silva Aquino,
   485 K.A., 2021. Valorizing municipal organic waste to produce biodiesel, biogas, organic fertilizer,
- 486 and value-added chemicals: an integrated biorefinery approach. Biomass Conversion and
- 487 Biorefinery, pp.1-15.

- 488 13- Chen, T., Qiu, X., Feng, H., Yin, J. and Shen, D., 2021. Solid digestate disposal strategies to
  489 reduce the environmental impact and energy consumption of food waste-based biogas systems.
  490 Bioresource Technology, 325, p.124706.
- 491 14- Yong, Z.J., Bashir, M.J. and Hassan, M.S., 2021. Biogas and biofertilizer production from
  492 organic fraction municipal solid waste for sustainable circular economy and environmental
  493 protection in Malaysia. Science of The Total Environment, 776, p.145961.
- 494 15-Su, B., Wang, H., Zhang, X., He, H. and Zheng, J., 2021. Using photovoltaic thermal
  495 technology to enhance biomethane generation via biogas upgrading in anaerobic digestion.
  496 Energy Conversion and Management, 235, p.113965.
- 497 16- Sarkar, O., Santhosh, J., Dhar, A. and Mohan, S.V., 2021. Green hythane production from food
  498 waste: Integration of dark-fermentation and methanogenic process towards biogas up499 gradation. International Journal of Hydrogen Energy, 46(36), pp.18832-18843.
- 17- Avila, R., Carrero, E., Vicent, T. and Blánquez, P., 2021. Integration of enzymatic pretreatment
   and sludge co-digestion in biogas production from microalgae. Waste Management, 124,
   pp.254-263.
- 503 18-Dinnebier, H.C.F., Matthiensen, A., Michelon, W., Tápparo, D.C., Fonseca, T.G., Favretto, R.,
  504 Steinmetz, R.L.R., Treichel, H., Antes, F.G. and Kunz, A., 2021. Phycoremediation and
  505 biomass production from high strong swine wastewater for biogas generation improvement:
  506 An integrated bioprocess. Bioresource Technology, 332, p.125111.
- 507 19-Boffardi, R., De Simone, L., De Pascale, A., Ioppolo, G. and Arbolino, R., 2021. Best508 compromise solutions for waste management: Decision support system for policymaking.
  509 Waste Management, 121, pp.441-451.
- 20- Kim, S., Mostafa, A., Im, S., Lee, M.K., Kang, S., Na, J.G. and Kim, D.H., 2021. Production
  of high-calorific biogas from food waste by integrating two approaches: Autogenerative highpressure and hydrogen injection. Water Research, 194, p.116920.
- 21- Ajieh, M.U., Isagba, E.S., Ihoeghian, N., Edosa, V.I., Amenaghawon, A., Oshoma, C.E.,
  Erhunmwunse, N., Obuekwe, I.S., Tongo, I., Emokaro, C. and Ezemonye, L.I., 2021.
  Assessment of sociocultural acceptability of biogas from faecal waste as an alternative energy
  source in selected areas of Benin City, Edo State, Nigeria. Environment, Development and
  Sustainability, pp.1-18.
- 22- Chowdhury, H., Chowdhury, T., Miskat, M.I., Hossain, N., Chowdhury, P. and Sait, S.M.,
  2021. Potential of biogas and bioelectricity production from Rohingya camp in Bangladesh: A
  case study. Energy, 214, p.118837.
- 521 23-Llano, T., Arce, C. and Finger, D.C., 2021. Optimization of biogas production through
  522 anaerobic digestion of municipal solid waste: a case study in the capital area of Re ykjavik,
  523 Iceland. Journal of Chemical Technology & Biotechnology, 96(5), pp.1333-1344.
- 524 24- Cavaignac, R.S., Ferreira, N.L. and Guardani, R., 2021. Techno-economic and environmental
  process evaluation of biogas upgrading via amine scrubbing. Renewable Energy, 171, pp.868526 880.

- 527 25-Miranda, I.T.P., Moletta, J., Pedroso, B., Pilatti, L.A. and Picinin, C.T., 2021. A Review on
  528 Green Technology Practices at BRICS Countries: Brazil, Russia, India, China, and South
  529 Africa. SAGE Open, 11(2), p.21582440211013780.
- 26-Niu, S., Dai, R., Zhong, S., Wang, Y., Qiang, W. and Dang, L., 2021. Multiple benefit
  assessment and suitable operation mechanism of medium-and large-scale biogas projects for
  cooking fuel in rural Gansu, China. Sustainable Energy Technologies and Assessments, 46,
  p.101285.
- 27- Abanades, S., Abbaspour, H., Ahmadi, A., Das, B., Ehyaei, M.A., Esmaeilion, F., Assad,
  M.E.H., Hajilounezhad, T., Jamali, D.H., Hmida, A. and Ozgoli, H.A., 2021. A critical review
  of biogas production and usage with legislations framework across the globe. International
  Journal of Environmental Science and Technology, pp.1-24.
- 28-Lomazov, V.A., Lomazova, V.I., Miroshnichenko, I.V., Petrosov, D.A. and Mironov, A.L.,
  2021, February. Optimum planning of experimental research at the biogas plant. In IOP
  Conference Series: Earth and Environmental Science (Vol. 659, No. 1, p. 012111). IOP
  Publishing.
- 542 29-Stürmer, B., Leiers, D., Anspach, V., Brügging, E., Scharfy, D. and Wissel, T., 2021.
  543 Agricultural biogas production: A regional comparison of technical parameters. Renewable
  544 Energy, 164, pp.171-182.
- 30- Jung, S., Lee, J., Moon, D.H., Kim, K.H. and Kwon, E.E., 2021. Upgrading biogas into syngas
  through dry reforming. Renewable and Sustainable Energy Reviews, 143, p.110949.
- 31- Akbulut, A., Arslan, O., Arat, H. and Erbaş, O., 2021. Important aspects for the planning of
  biogas energy plants: Malatya case study. Case Studies in Thermal Engineering, 26, p.101076.
- 32- Brémond, U., Bertrandias, A., de Buyer, R., Latrille, E., Jimenez, J., Escudié, R., Steyer, J.P.,
  Bernet, N. and Carrere, H., 2021. Recirculation of solid digestate to enhance energy efficiency
  of biogas plants: Strategies, conditions and impacts. Energy Conversion and Management, 231,
  p.113759.
- 33-Naquash, A., Qyyum, M.A., Haider, J., Lim, H. and Lee, M., 2021. Renewable LNG
  production: Biogas upgrading through CO2 solidification integrated with single-loop mixed
  refrigerant biomethane liquefaction process. Energy Conversion and Management, 243,
  p.114363.
- 34- Zhang, J., Gu, D., Chen, J., He, Y., Dai, Y., Loh, K.C. and Tong, Y.W., 2021. Assessment and
   optimization of a decentralized food-waste-to-energy system with anaerobic digestion and
   CHP for energy utilization. Energy Conversion and Management, 228, p.113654.
- 35- Wu, T., Bu, S., Wei, X., Wang, G. and Zhou, B., 2021. Multitasking multi-objective operation
   optimization of integrated energy system considering biogas-solar-wind renewables. Energy
   Conversion and Management, 229, p.113736.
- 36- Su, B., Wang, H., Zhang, X., He, H. and Zheng, J., 2021. Using photovoltaic thermal
  technology to enhance biomethane generation via biogas upgrading in anaerobic digestion.
  Energy Conversion and Management, 235, p.113965.

- 37- Hansen, A.D., Sorensen, P., Hansen, L.H. and Bindner, H., 2000. Models for a stand-alone PV
   system. Roskilde: Rio National Laboratory.
- 38- Sulaeman, S., Brown, E., Quispe-Abad, R. and Müller, N., 2021. Floating PV system as an
  alternative pathway to the amazon dam underproduction. Renewable and Sustainable Energy
  Reviews, 135, p.110082.
- 39-Lohani, S.P., Shakya, S., Gurung, P., Dhungana, B., Paudel, D. and Mainali, B., 2021.
  Anaerobic co-digestion of food waste, poultry litter and sewage sludge: seasonal performance
  under ambient condition and model evaluation. Energy Sources, Part A: Recovery, Utilization,
  and Environmental Effects, pp.1-16.
- 40- Ziaee, F., Mokhtarani, N. and Niavol, K.P., 2021. Solid-state anaerobic co-digestion of organic
  fraction of municipal waste and sawdust: impact of co-digestion ratio, inoculum-to-substrate
  ratio, and total solids. Biodegradation, pp.1-14.
- 41-Guo, Z., Usman, M., Alsareii, S.A., Harraz, F.A., Al-Assiri, M.S., Jalalah, M., Li, X. and
  Salama, E.S., 2021. Synergistic ammonia and fatty acids inhibition of microbial communities
  during slaughterhouse waste digestion for biogas production. Bioresource Technology,
  p.125383.
- 42- Eftekhari, M., Gheibi, M., Azizi-Toupkanloo, H., Hossein-Abadi, Z., Khraisheh, M.,
  Fathollahi-Fard, A.M. and Tian, G., 2021. Statistical optimization, soft computing prediction,
  mechanistic and empirical evaluation for fundamental appraisal of copper, lead and malachite
  green adsorption. Journal of Industrial Information Integration, 23, p.100219.
- 43- Gheibi, M., Karrabi, M. and Eftekhari, M., 2019. Designing a smart risk analysis method for
  gas chlorination units of water treatment plants with combination of Failure Mode Effects
  Analysis, Shannon Entropy, and Petri Net Modeling. Ecotoxicology and environmental safety,
  171, pp.600-608.
- 44- Amini, M.H., Arab, M., Faramarz, M.G., Ghazikhani, A. and Gheibi, M., 2021. Presenting a soft sensor for monitoring and controlling well health and pump performance using machine learning, statistical analysis, and Petri net modeling. Environmental Science and Pollution Research, pp.1-17.
- 45-Mohammadi, M., Gheibi, M., Fathollahi-Fard, A.M., Eftekhari, M., Kian, Z. and Tian, G.,
  2021. A hybrid computational intelligence approach for bioremediation of amoxicillin based
  on fungus activities from soil resources and aflatoxin B1 controls. Journal of Environmental
  Management, 299, p.113594.
- 46- Ghadami, N., Gheibi, M., Kian, Z., Faramarz, M.G., Naghedi, R., Eftekhari, M., FathollahiFard, A.M., Dulebenets, M.A. and Tian, G., 2021. Implementation of solar energy in smart
  cities using an integration of artificial neural network, photovoltaic system and classical Delphi
  methods. Sustainable Cities and Society, 74, p.103149.
- 47-Ghadirimoghaddam, D., Gheibi, M. and Eftekhari, M., 2021. Graphene oxide-cyanuric acid
   nanocomposite as a novel adsorbent for highly efficient solid phase extraction of Pb2+

- 604 followed by electrothermal atomic absorption spectrometry; statistical, soft computing and 605 mechanistic efforts. International Journal of Environmental Analytical Chemistry, pp.1-22.
- 48- Latifi, P., Karrabi, M. and Danesh, S., 2019. Anaerobic co-digestion of poultry slaughterhouse
  wastes with sewage sludge in batch-mode bioreactors (effect of inoculum-substrate ratio and
  total solids). Renewable and Sustainable Energy Reviews, 107, pp.288-296.
- 49- Rajendran, K., Aslanzadeh, S. and Taherzadeh, M.J., 2012. Household biogas digesters—A
  review. Energies, 5(8), pp.2911-2942.
- 50- Abatzoglou, N. and Boivin, S., 2009. A review of biogas purification processes. Biofuels,
  Bioproducts and Biorefining, 3(1), pp.42-71.
- 51- Mao, C., Feng, Y., Wang, X. and Ren, G., 2015. Review on research achievements of biogas
  from anaerobic digestion. Renewable and sustainable energy reviews, 45, pp.540-555.
- 52-Kougias, P.G. and Angelidaki, I., 2018. Biogas and its opportunities—A review. Frontiers of
  Environmental Science & Engineering, 12(3), pp.1-12.
- 53- Jiang, X., Sommer, S.G. and Christensen, K.V., 2011. A review of the biogas industry in China.
  Energy Policy, 39(10), pp.6073-6081.
- 619 54- Černý, M., Vítězová, M., Vítěz, T., Bartoš, M. and Kushkevych, I., 2018. Variation in the
  620 distribution of hydrogen producers from the clostridiales order in biogas reactors depending
  621 on different input substrates. Energies, 11(12), p.3270.
- 55-Metcalf & Eddy, Abu-Orf, M., Bowden, G., Burton, F.L., Pfrang, W., Stensel, H.D.,
  Tchobanoglous, G., Tsuchihashi, R. and AECOM (Firm), 2014. Wastewater engineering:
  treatment and resource recovery. McGraw Hill Education.
- 56- SONG, J.L., RUAN, Z.Y., HU, G.Q., JIANG, R.B., LIU, X.F. and XU, F.H., 2010. Microbial
  diversity and community composition in biogas sludge and its enriched product. China Biogas,
  28(2), pp.3-11.
- 57- Kapoor, R., Ghosh, P., Kumar, M., Sengupta, S., Gupta, A., Kumar, S.S., Vijay, V., Kumar,
  V., Vijay, V.K. and Pant, D., 2020. Valorization of agricultural waste for biogas based circular
  economy in India: A research outlook. Bioresource technology, 304, p.123036.
- 58- Makisha, N., 2016. Waste water and biogas–ecology and economy. procedia engineering, 165,
   pp.1092-1097.
- 59- Anyaoku, C.C. and Baroutian, S., 2018. Decentralized anaerobic digestion systems for
  increased utilization of biogas from municipal solid waste. Renewable and Sustainable Energy
  Reviews, 90, pp.982-991.
- 636 60- Lohani, S.P., Dhungana, B., Horn, H. and Khatiwada, D., 2021. Small-scale biogas technology
  637 and clean cooking fuel: Assessing the potential and links with SDGs in low-income countries–
  638 A case study of Nepal. Sustainable Energy Technologies and Assessments, 46, p.101301.
- 639 61- Sogn, T.A., Dragicevic, I., Linjordet, R., Krogstad, T., Eijsink, V.G. and Eich-Greatorex, S.,
- 640 2018. Recycling of biogas digestates in plant production: NPK fertilizer value and risk of
- 641 leaching. International Journal of Recycling of Organic Waste in Agriculture, 7(1), pp.49-58.

642 62- Liang, F., Xu, L., Ji, L., He, Q., Wu, L. and Yan, S., 2021. A new approach for biogas slurry
643 disposal by adopting CO2-rich biogas slurry as the flower fertilizer of Spathiphyllum:
644 Feasibility, cost and environmental pollution potential. Science of The Total Environment,
645 770, p.145333.

- 646 63- Hakawati, R., Smyth, B.M., McCullough, G., De Rosa, F. and Rooney, D., 2017. What is the
  647 most energy efficient route for biogas utilization: heat, electricity or transport?. Applied
- 648 Energy, 206, pp.1076-1087.
- 649