ROLE OF LOGISTICS IN RENEWABLE ENERGY AND SUSTAINABILITY

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ABSTRACT

The research provides a comprehensive analysis of the crucial role of logistics in renewable energy and sustainability. It covers renewable energy sources, environmental impacts, and logistics in sustainable development. The study investigates reverse logistics, warehousing, supply chain management, and transportation in the renewable energy industry. In the context of renewable energy, it highlights the significance of biodiesel and used cooking oil (UCO) logistics. Case studies provide successful examples and best practices. The research concludes with recommendations for the future, including collaboration, innovation, and policy support.

This research provides an extensive overview of the critical role logistics plays in promoting renewable energy and sustainability. It addresses the challenges in transporting and installing renewable energy infrastructure across vast areas, emphasizing the need for efficient supply chain management. Logistics is identified as crucial for enabling energy storage solutions, ensuring a stable power supply from intermittent renewable sources. Additionally, adopting greener transportation methods and circular logistics strategies can significantly reduce the carbon footprint associated with renewable energy. The research highlights the importance of data-driven logistics and smart technologies in optimizing renewable energy logistics. Overall, it emphasizes that efficient logistics is essential for advancing renewable energy deployment and achieving a more sustainable energy future.

Keywords: logistics, renewable energy, sustainability, environmental impact, supply chain,

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INTRODUCTION

By 2027, it is anticipated that the global market for used cooking oil (UCO) will have grown to $13.5 billion. This growth is being driven by the increasing demand for sustainable fuels and the rising awareness of the environmental benefits of using UCO to produce biodiesel. The logistics of UCO collection and export is a complex and challenging process. UCO is a hazardous material that must be handled and transported with care. The logistics industry plays a critical role in ensuring that UCO is collected and transported safely and efficiently. This summer internship will explore the role of logistics in the UCO industry.

- The collection and transportation of UCO: The internship will look into the difficulties and possibilities related to the collecting and delivery of UCO. The internship will also develop recommendations for improving the efficiency and effectiveness of UCO logistics.
- The regulatory environment for UCO logistics: The internship will examine the regulatory environment for UCO logistics. The internship will also identify opportunities to improve the regulatory framework for UCO logistics.
- The future of UCO logistics: The internship will explore the future of UCO logistics. The internship will identify emerging trends in UCO logistics and develop recommendations for how the logistics industry can adapt to these trends.

The internship will be conducted in India, where the UCO industry is rapidly growing. The internship will provide the opportunity to gain experience in a developing market and to contribute to the development of sustainable solutions for the UCO industry. This introduction is elusive because it does not provide any concrete details about the internship. Instead, it creates a sense of mystery and intrigue by highlighting the challenges and opportunities associated with the UCO industry. The introduction also hints at the future of UCO logistics, which is a topic that is not well-understood.

Chapter 1

Renewable Energy and Sustainability: An Overview

Renewable energy sources, such as solar, wind, hydropower, and biomass energy, are essential for combating global warming and fostering sustainability. Solar energy uses photovoltaic panels and concentrated solar power systems to harness the sun's rays to produce electricity. Wind energy uses wind turbines to transform the kinetic energy of the wind into electricity. Produced from organic materials, biomass energy can be used to generate heat, electricity, and biofuels. The future of energy will be cleaner and more sustainable thanks to these environmentally beneficial substitutes for fossil fuels.

Chapter 2

Renewable Energy Sector in Logistics

The conception, execution, and operation of renewable energy projects all depend heavily on logistics. The major functions of logistics in the field of renewable energy are examined in this part, including waste management, reverse logistics, warehousing and distribution, transportation of renewable energy equipment, and supply chain management. Examples of actual users in various roles are given.

Transportation of Renewable Energy Equipment:

Transporting huge, heavy equipment, such as wind turbines, solar panels, and hydropower components, is a common requirement for renewable energy projects. In order to guarantee the timely and safe transportation of this equipment to project sites, logistics companies are essential.

Supply Chain Management:

Logistics providers are responsible for coordinating suppliers, managing inventory, and optimizing transportation routes to minimize delays and costs.

Warehousing and Distribution:

Logistics companies provide storage facilities, inventory management systems, and distribution services to ensure that project operators have access to the necessary resources.

Reverse Logistics and Waste Management:

Logistics providers play a role in facilitating the reverse logistics of decommissioned equipment, recycling or disposing of waste materials, and ensuring compliance with environmental regulations.

Chapter 3

Challenges and Solutions in Renewable Energy Logistics

Renewable energy logistics face several challenges that require careful planning and execution. This section explores some common challenges in renewable energy logistics, including complex project coordination, infrastructure requirements, regulatory compliance, and risk management. Real-life examples demonstrate how these challenges have been addressed.

1. Complex Project Coordination:

Renewable energy projects often involve multiple stakeholders, including developers, equipment manufacturers, logistics providers, and construction teams. Coordinating the various activities and ensuring seamless collaboration among these stakeholders can be challenging.

2. Infrastructure Requirements:

Renewable energy projects require adequate infrastructure to support the transportation and installation of large-scale equipment. This includes specialized ports, roads, and storage facilities. Insufficient infrastructure can lead to delays and increased costs.

3. Regulatory Compliance:

Renewable energy logistics must adhere to various regulations, permits, and environmental standards. Compliance with these requirements can be complex and time-consuming, requiring careful monitoring and documentation.

4. Risk Management:

Renewable energy logistics involves inherent risks such as adverse weather conditions, transportation accidents, and equipment failures. Managing these risks is crucial to ensure the safety of personnel, protect the environment, and minimize project disruptions.

Chapter 4

Biodiesel: An Efficient Vertical of Renewable Energy

A renewable energy source called biodiesel is created from organic ingredients like vegetable or animal fats. This section explores biodiesel's production process and benefits, as well as the supply chain considerations and logistics challenges faced in its transportation. Real case examples showcase how these challenges have been addressed.

1. Production Process and Benefits of Biodiesel:

The production process involves converting organic materials into biodiesel through a chemical reaction called transesterification. Reduced greenhouse gas emissions, better air quality, and less reliance on fossil fuels are all advantages of biodiesel.

2. Supply Chain Considerations for Biodiesel:

Raw Material Procurement: Procuring sufficient and high-quality feedstock is crucial for bio-diesel production. This involves establishing relationships with farmers, waste management companies, and other suppliers.

Processing and Refining: The conversion of feedstock into biodiesel requires specialized processing facilities and refining techniques. Ensuring the availability of these facilities is important for the supply chain.

Quality Control and Certification: Adhering to quality control measures and obtaining certifications, such as the ASTM D6751 standard, is essential to ensure the biodiesel meets industry specifications.

3. Logistics Challenges and Solutions in Bio-diesel Transportation:

Storage and Handling: Biodiesel has specific storage and handling requirements to maintain its quality. Challenges may arise in terms of temperature control, contamination prevention, and proper labeling.

Transportation Infrastructure: Bio-diesel transportation requires a well-maintained infrastructure to accommodate tanker trucks or railcars. Challenges can include limited availability of dedicated bio-diesel Regulatory Compliance: Compliance with regulations and certifications related to transportation, such as hazardous material handling and transport permits, is crucial for bio-diesel logistics.

Chapter 5

Market Alignment of Biodiesel

Market analysis and understanding the demand for biodiesel are crucial for the successful implementation and growth of biodiesel as a renewable energy source. This section explores market analysis, market trends, and marketing strategies for biodiesel products.

1. Market Analysis and Demand for Biodiesel:

- Assess market size and potential through market research.
- Identify target market segments with high demand, such as transportation, agriculture, and industrial sectors.
- Analyze consumer behavior to understand preferences, awareness, and willingness to adopt biodiesel.
- Evaluate government policies, incentives, and regulations to gauge their impact on the biodiesel market.

2. Market Trends and Opportunities:

- Increasing Environmental Awareness: Demand for cleaner and more sustainable fuel options like biodiesel is rising due to concerns about climate change and air pollution.

- Government Support and Renewable Energy Targets: Countries establishing renewable energy targets and providing incentives or blending mandates create opportunities for biodiesel.
- Technological Advancements: Continuous advancements in production technologies and feedstock options improve biodiesel's efficiency and cost-effectiveness, driving market growth.
- Sustainability Certification: Growing demand for certified biodiesel meeting standards like RSB offers market differentiation and access to environmentally conscious customers.

3. Marketing Strategies for Biodiesel Products:

- Branding and positioning: Create a powerful brand identity that emphasizes the advantages of biodiesel for the environment and sustainability.
- Education and knowledge: Launch educational initiatives to raise consumer, company, and policymaker knowledge of the benefits and favorable environmental impact of biodiesel.
- Supply Chain Collaboration: Collaborate with fuel retailers, distributors, and fleet operators to ensure biodiesel availability at fueling stations.
- Pricing and Incentives: Implement competitive pricing strategies and leverage government incentives or tax credits to encourage biodiesel adoption.
- Strategic Partnerships: Form strategic partnerships with agricultural organizations, fuel industry stakeholders, and vehicle manufacturers to promote and integrate biodiesel into their operations.

Through market analysis, understanding trends, and effective marketing strategies, the biodiesel industry can align its products with market demands and capitalize on opportunities for growth and sustainability.

Literature Review

2. From Used Cooking Oil to biodiesel.
Full Supply Chain demonstration
From Used Cooking Oil to biodiesel.
Full Supply Chain demonstration
2. From Used Cooking Oil to biodiesel.
Full Supply Chain demonstration
2. From Used Cooking Oil to biodiesel.
Full Supply Chain demonstration

1. Montserrat Ceron Ferrusca, Rubi Romero, Sanda Luz Martinez,.., " Production of Biodiesel from Used Cooking Oil: A View of Catalytic Processes", 11(7), 1952,[2023] [10]

Cooking oil (WCO) has shown promise as a feedstock for the synthesis of biodiesel, but it is not without difficulties due to its high level of free fatty acids (FFA) and problems with the catalysts employed in the process. The scientific community is investigating the use of bifunctional catalysts that can concurrently esterify free fatty acids and triglycerides in WCO to solve these constraints.

2. M. Suresh, C.P. Jawahar, Arun Richard, "A review on biodiesel production, combustion, performance, emission characteristics of non-edible oils in variable compression ratio diesel engine using biodiesel", Volume 92, Pages 38-49, [2018] [8]

In this study, combustion, performance, and emission characteristics of a biodiesel- and variable compression ratio (VCR) diesel engine are measured. In comparison to a constant compression ratio diesel engine, the VCR engine has benefits such as improved fuel efficiency, a 30% reduction in fuel consumption, improved control at peak cylinder pressure, the possibility to use diverse fuels, and lower exhaust emissions.

3. Nana Geng, Yong Zhang, Yixiang Sun, Shuchao Geng , "Optimization of biodiesel Supply Chain produced from Waste Cooking Oil- A case study in China", 10.1088/1755-1315/264/1/012006, [2019] [4]

The design and improvement of a supply chain for the conversion of WCO to biodiesel is the main focus of the article. In order to decide on site, manufacturing, inventory, and distribution under various situations, it builds an advanced modeling framework.The research proposes a four-stage model to improve the biodiesel supply chain by taking into account both economic and environmental goals.

4. Emma Lindkvist, Magnus Larlsson, Jenny Ivner, "System Analysis of Biogas Production—Part II Application in Food Industry Systems", 12(3), 412, [2019], [3]

This study indicate that converting organic by-products from the food industry into biogas offers a beneficial option, particularly when considering reduction of greenhouse gas emissions. The choice of treatment method for these by-products can significantly impact their potential as a valuable resource for energy recovery.

5. Takase, Mohammed, Zhao, Ting, Zhang, Min, Chen, Yao, Liu, Hongyang, Yang, Liuqing, Wu, Xiangyang "An expatiate review of neem, jatropha, rubber and karanja as multipurpose

non-edible biodiesel resources", vol. 43(C), pages 495-520, [2015] [7]

The increasing demand for petroleum due to global industrialization and modernization, which has led to the depletion of fossil fuel reserves and rising prices. In response to these challenges and concerns about food insecurity, researchers are seeking alternative fuels that can be derived from renewable sources.

6. Kumar Saurabh, Rudrodip Majumdar," Conceptualizing Integrated Life-Cycle Management for Sustainable And Optimal Utilization of Used Cooking Oil(UCO)", SEEC2022_098, [2022] [5]

Used cooking oil (UCO) has a comprehensive life-cycle concept that includes social, environmental, and economic benefits. The UCO supply chain must be managed more effectively, with strict adherence to standards and the deployment of contemporary technologies, in order to fully achieve these benefits. Implementation success depends on efficient cooperation across multiple ministries and government agencies.

7. Zacharias Gkouskos, Stavroula Tournaki, M P Giamalaki, Theocharis D Tsoutsos, "From Used Cooking Oil to biodiesel. Full Supply Chain demonstration", 643-654, [2018] [2]

The project focuses on creating sustainable energy supply chains, planning effective renewable energy development, and fostering small local enterprises. To encourage the use of renewable energy sources and energy efficiency measures, it performs 15 pilot demonstration actions.

8. Kannan Govindan, A. Rajeev, Sidhartha S. Padhi, Rupesh K. Pati," Supply chain sustainability and performance of firms: A meta-analysis of the literature", Volume 137,101923,[2020] [9]

The study reveals a beneficial relationship between sustainable supply chain practices and company performance, showing that businesses gain from incorporating sustainable supply chain strategies. The data also indicates that there has been a gradual increase in the strength of the link between sustainability practices and company performance.

9. Giovanni De Feo, Aurelio Di Domenico, Carmen Ferrara, Salvatore Abate, Libero Sesti Osseo," Evolution of Waste Cooking Oil Collection in an Area with Long-Standing Waste Management Problems", 12(20), 8578, [2020], [6]

The study highlights the value of informational and awareness raising efforts as well as the right way to entrust the collection service, particularly in regions with a history of waste management issues.

10. Sanjib Kumar Karmee, Raffel Dharma Patria, Carol Sze Ki Lin, "Techno-Economic Evaluation of Biodiesel Production from Waste Cooking Oil—A Case Study of Hong Kong", 16(3), 4362-4371,[2018] [11]

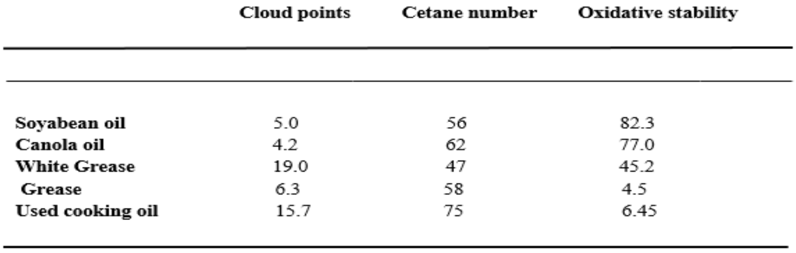
The manufacture of biodiesel utilizing acid and base catalysts exhibits resistance to changes in WCO and biodiesel pricing, making it a more reliable economic choice. Compared to the average price of biodiesel in Hong Kong, the usage of acid and base catalysts for biodiesel production is less expensive. The acid-catalyzed approach is the one that is shown to be the most economical for producing biodiesel among the available catalyst alternatives.

Data Collection and Analysis

Recycled cooking oil and animal fats. Different feedstocks produce biodiesel with different quantities that must be considered.

Refined vegetable oils, soyabean oil, canola oil, grease, have been the most common biodiesel feedstock.
This biodiesel feedstocks input between 2017 and 2019. Used cooking oil use for biodiesel production about 20% from 2017 to 2019.

Properties of Biodiesel from feedstock



	Cloud points	Cetane number	Oxidative stability
Soyabean oil	5.0	56	82.3
Canola oil	4.2	62	77.0
White Grease	19.0	47	45.2
Grease	6.3	58	4.5
Used cooking oil	15.7	75	6.45

Figure 1: *Table for biodiesel contents*

The characteristics of biodiesel are different among various feedstocks and their equivalent.

The cloud point refers to temperature (from wax to fuel).

The cetane number is an indicator of fuel's propensity.

This is basically a general collection of many components used by biodiesel.

Representation of Used cooking oil

A pie chart is a circular chart divided into sectors, each representing a specific category or data point. In this case, we are using a pie chart to depict information about the currently used, previously used, and predicted use of cooking oil.

1. Currently Used Cooking Oil:
This sector of the pie chart represents the percentage or proportion of cooking oil that is currently being used for cooking purposes. It includes all the different types of cooking oil that are currently in use by individuals, households, or businesses.

2. Previously Used Cooking Oil:
This sector of the pie chart represents the percentage or proportion of cooking oil that has been used for cooking purposes in the past but is no longer being used. It includes cooking oil that has been discarded or replaced with new oil.

3. Predicted Use of Cooking Oil:
This sector of the pie chart represents the percentage or proportion of cooking oil that is estimated or predicted to be used in the future for cooking purposes. This prediction may be based on trends, consumption patterns, or other relevant factors.

The pie chart visually presents the distribution of these three categories, allowing us to understand the current, past, and anticipated usage of cooking oil. The sum of the three sectors will add up to 100%, as the entire chart represents the total consumption of cooking oil over the defined period.

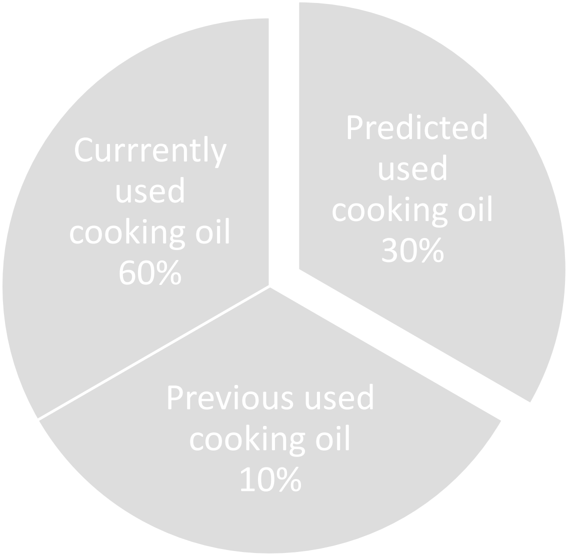


Figure 2: *Pie chart of UCO*

1. Use of Used Cooking Oil as a Feedstock for Biodiesel: An Overview

- A renewable resource is UCO. UCO is a byproduct of cooking that is produced in homes, restaurants, and food manufacturing facilities. Recyclable waste can be converted into biodiesel, reducing reliance on fossil fuels.
- Environmental Benefits: Utilizing UCO for biodiesel production helps reduce waste and prevents improper disposal, which can have harmful effects on the environment.
- Feedstock Characteristics: UCO has specific properties such as high free fatty acid content and impurities, which require proper processing and treatment before conversion into biodiesel.

2. Collection and Handling of UCO:

- Source Identification: Establishing collection networks and partnerships with restaurants, food establishments, and households to source UCO.

- Efficient Collection Systems: Implementing efficient collection systems to ensure timely and hygienic collection of UCO, including designated collection points and scheduled pickups.
- Storage and Transport: Proper storage and transportation methods to maintain the quality of UCO and prevent contamination or degradation.

3. Quality Control and Compliance in UCO Collection:
- Sampling and Testing: Implementing sampling and testing procedures to assess the quality and suitability of UCO for biodiesel production, including testing for acidity, moisture content, and impurities.
- Compliance with Regulations: Adhering to local regulations and standards for UCO collection, storage, and transportation to ensure environmental and safety compliance.
- Traceability and Documentation: Establishing traceability systems to track the origin, collection, and handling of UCO, along with proper documentation to demonstrate compliance.

Future Predictions

The utilization of leftover cooking oil into biodiesel is one of the most viable and long-term strategies for solving environmental issues and lowering our carbon footprint in the future. A cleaner-burning, renewable alternative to traditional fossil fuels, biodiesel has the potential to completely transform the energy landscape and usher in a more sustainable future. Here are some informative points regarding the future prediction of used cooking oil as biodiesel:

1. Environmental Benefits: The utilization of used cooking oil as biodiesel offers substantial environmental benefits. We can considerably cut greenhouse gas emissions, a major factor in climate change, by turning this waste product into a useful energy source.

2. Waste Reduction: As the world grapples with increasing waste generation, repurposing used cooking oil as biodiesel presents an efficient way to manage waste. Instead of clogging landfills or causing environmental hazards, converting this waste into a useful resource helps alleviate the burden on waste management systems.

3. Energy Independence: Increased energy independence is a result of using leftover cooking oil as a feedstock for the manufacturing of biodiesel. Because biodiesel is made from renewable resources, it lessens our reliance on finite fossil fuel stocks, promoting energy security and enhancing resilience to changes in the world energy market.

4. Sustainable Agriculture: Using leftover cooking oil to make biodiesel encourages the use of sustainable agriculture methods. The cultivation of energy crops expressly for the generation of biodiesel may be encouraged as the demand for biodiesel rises. The ability to cultivate these crops on marginal lands prevents them from competing with food crops and encourages sustainable land use.

5. Economic Opportunities: The biodiesel industry offers economic opportunities for local communities and entrepreneurs. The collection, processing, and distribution of used cooking oil for biodiesel production can create jobs and stimulate economic growth in various regions.

6. Government Support and Incentives: Many governments worldwide are recognizing the potential of biodiesel and are offering various incentives and support mechanisms to encourage its adoption. These may include tax credits, grants, and renewable energy standards, driving investment and innovation in the biodiesel sector.

7. Technological Advancements: Ongoing research and technological advancements in biodiesel production processes are improving efficiency, reducing costs, and increasing the overall viability of using used cooking oil as a feedstock. This will further enhance the competitiveness and attractiveness of biodiesel as a renewable energy option.

In this section, we will predict the biodiesel decision in India on account of secondary data extracted using the Regression model in R.

Manure samples from the Tata Oil Farm that were collected in December 2020 and February 2021 and initially held at -10°C are used in this. We listed the following in the excel file format: Essay, Biogas, Temperature, Manure, Ratio, pH, and OLR.

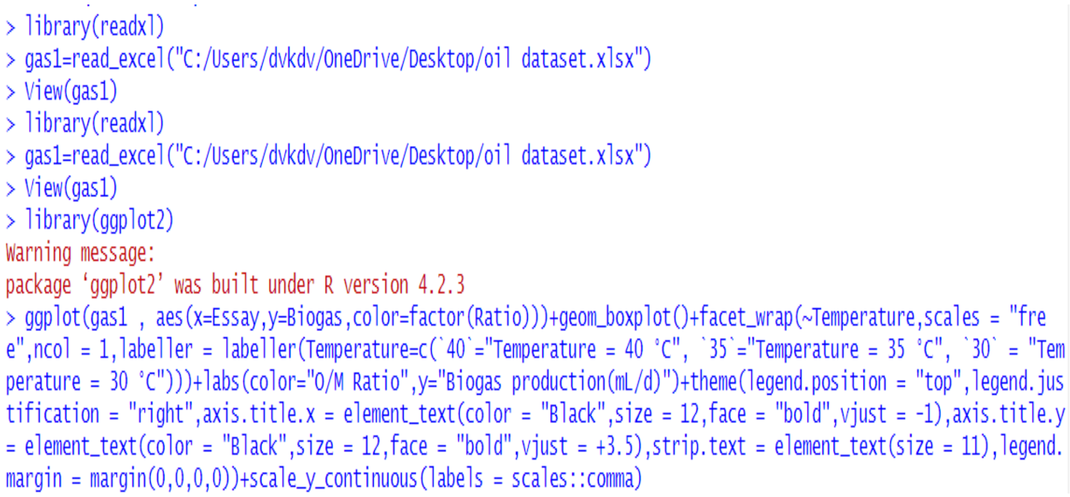
In this there are 247 observations and 7 variables. So, showing the content we showed you starting 5 data values.

In device ("C:/Users/dvkdv/OneDrive/Desktop/oil dataset.xlsx")library(readxl) gas1=read_excel ("C:/Users/dvkdv/OneDrive/Desktop/oil dataset.xlsx") View(gas1) head(gas1)

Essay	Biogas	Temperature	Manure	Ratio	pH	OLR
M2R0	1954	40	2	0	7.5	2
M2R0	211	40	2	0	7.5	2
M2R0		40	2	0	7.5	2
M2R0	2018	40	2	0	7.5	2
M2R0	1963	40	2	0	7.5	2

***Figure 3:** Table of biogas observation(head(gas))*

GGPLOT



```
> library(readxl)
> gas1=read_excel("C:/Users/dvkdv/OneDrive/Desktop/oil dataset.xlsx")
> View(gas1)
> library(readxl)
> gas1=read_excel("C:/Users/dvkdv/OneDrive/Desktop/oil dataset.xlsx")
> View(gas1)
> library(ggplot2)
Warning message:
package ‘ggplot2’ was built under R version 4.2.3
> ggplot(gas1 , aes(x=Essay,y=Biogas,color=factor(Ratio)))+geom_boxplot()+facet_wrap(~Temperature,scales = "fre
e",ncol = 1,labeller = labeller(Temperature=c(`40`="Temperature = 40 °C", `35`="Temperature = 35 °C", `30` = "Tem
perature = 30 °C")))+labs(color="O/M Ratio",y="Biogas production(mL/d)")+theme(legend.position = "top",legend.jus
tification = "right",axis.title.x = element_text(color = "Black",size = 12,face = "bold",vjust = -1),axis.title.y
 = element_text(color = "Black",size = 12,face = "bold",vjust = +3.5),strip.text = element_text(size = 11),legend.
margin = margin(0,0,0,0))+scale_y_continuous(labels = scales::comma)
```

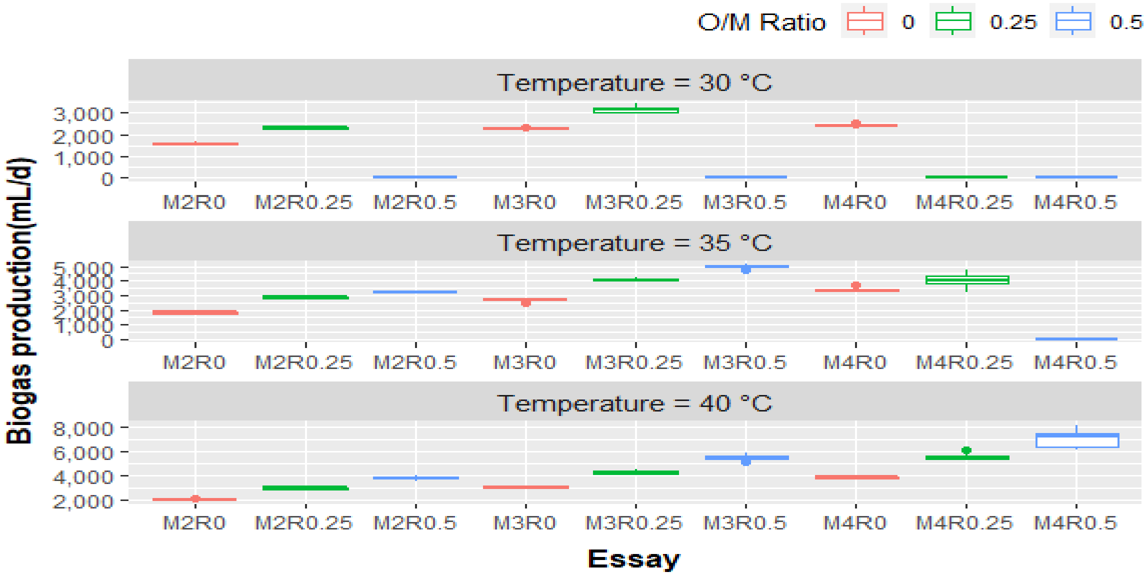
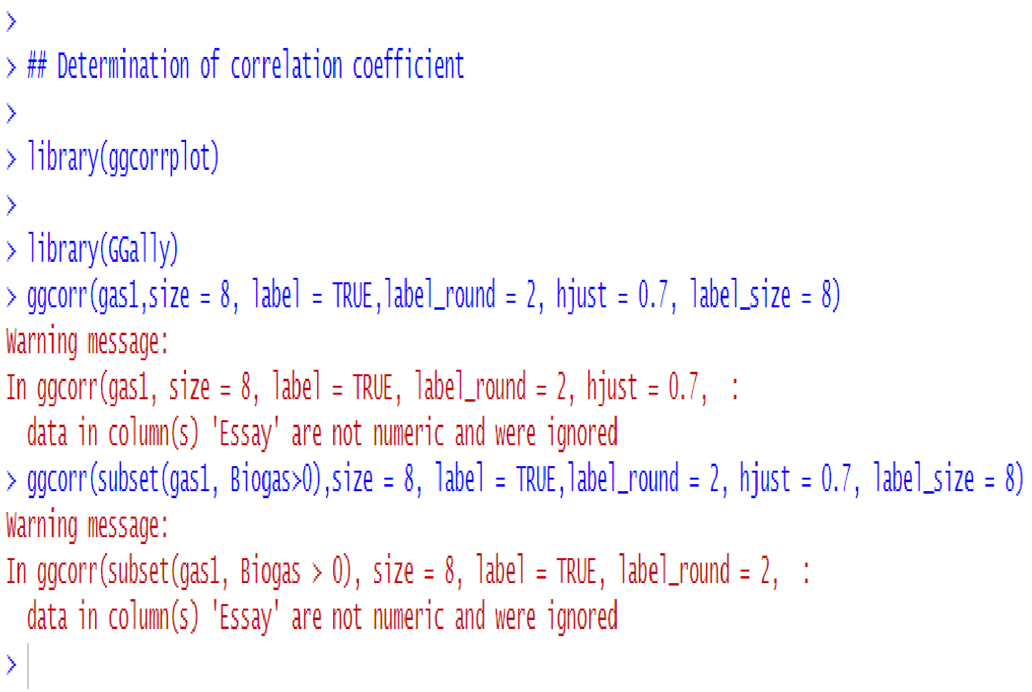


***Figure 4:**Biogas production at different temperature level*

#Determination of correlation coefficients



```
>
> ## Determination of correlation coefficient
>
> library(ggcorrplot)
>
> library(GGally)
> ggcorr(gas1,size = 8, label = TRUE,label_round = 2, hjust = 0.7, label_size = 8)
Warning message:
In ggcorr(gas1, size = 8, label = TRUE, label_round = 2, hjust = 0.7,  :
  data in column(s) 'Essay' are not numeric and were ignored
> ggcorr(subset(gas1, Biogas>0),size = 8, label = TRUE,label_round = 2, hjust = 0.7, label_size = 8)
Warning message:
In ggcorr(subset(gas1, Biogas > 0), size = 8, label = TRUE, label_round = 2,  :
  data in column(s) 'Essay' are not numeric and were ignored
> 
```

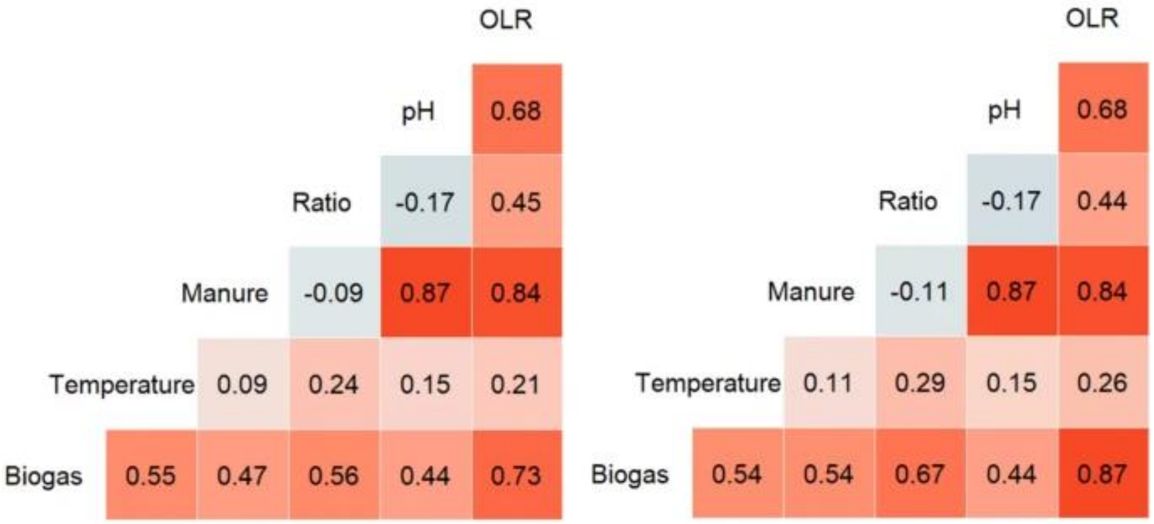
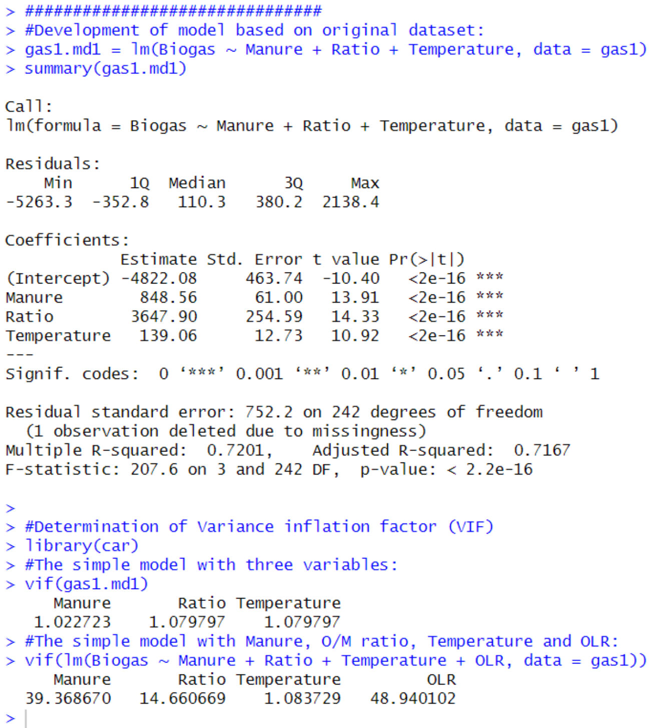


Figure 5: *pH level of oil*

################################

#**Determination of Variance inflation factor (VIF)**
library(car)
#The simple model with three variables:
vif(gas1.md1)

#The simple model with Manure, O/M ratio, Temperature and OLR:
vif(lm(Biogas ~ Manure + Ratio + Temperature + OLR, data = gas1))

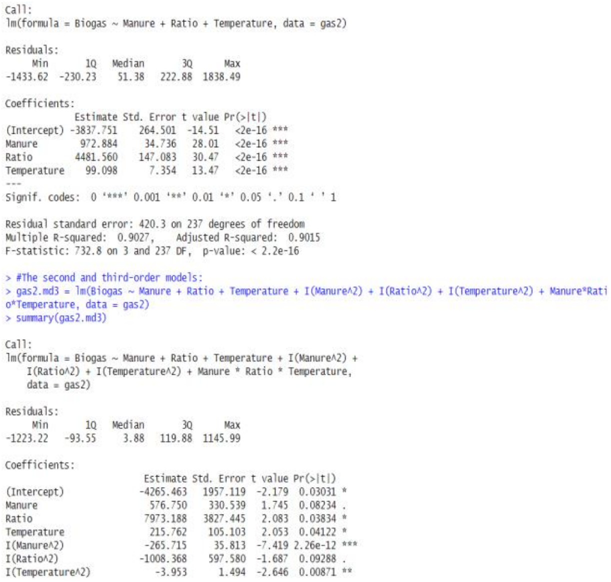


```
> ###############################
> #Development of model based on original dataset:
> gas1.md1 = lm(Biogas ~ Manure + Ratio + Temperature, data = gas1)
> summary(gas1.md1)

Call:
lm(formula = Biogas ~ Manure + Ratio + Temperature, data = gas1)

Residuals:
    Min      1Q  Median      3Q     Max 
-5263.3  -352.8   110.3   380.2  2138.4 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) -4822.08     463.74  -10.40   <2e-16 ***
Manure        848.56      61.00   13.91   <2e-16 ***
Ratio        3647.90     254.59   14.33   <2e-16 ***
Temperature   139.06      12.73   10.92   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 752.2 on 242 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared:  0.7201,	Adjusted R-squared:  0.7167 
F-statistic: 207.6 on 3 and 242 DF,  p-value: < 2.2e-16

> 
> #Determination of Variance inflation factor (VIF)
> library(car)
> #The simple model with three variables:
> vif(gas1.md1)
     Manure       Ratio Temperature 
   1.022723    1.079797    1.079797 
> #The simple model with Manure, O/M ratio, Temperature and OLR:
> vif(lm(Biogas ~ Manure + Ratio + Temperature + OLR, data = gas1))
     Manure       Ratio Temperature         OLR 
  39.368670   14.660669    1.083729   48.940102 
> 
```

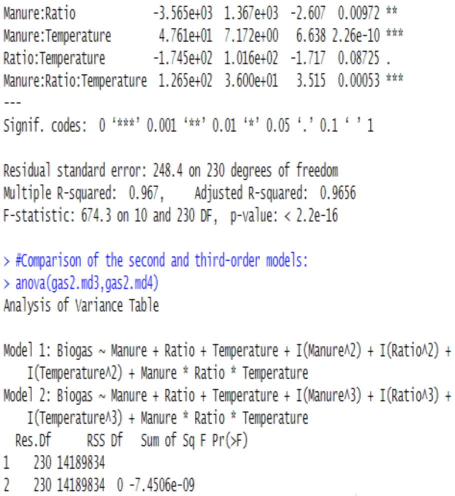
################################

#Comparison of the second and third-order models:

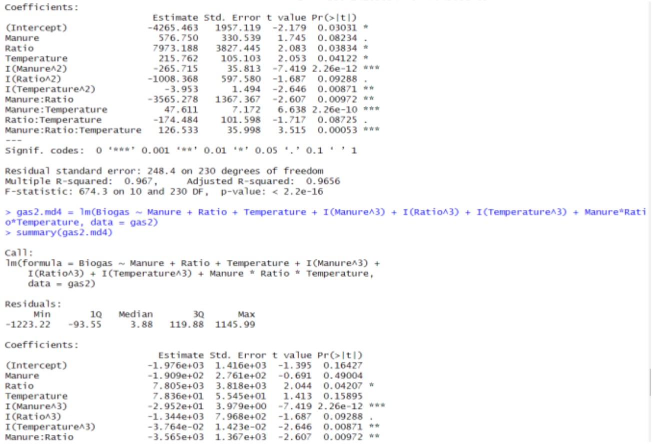
ANOVA(gas2.md3, gas2.md4)



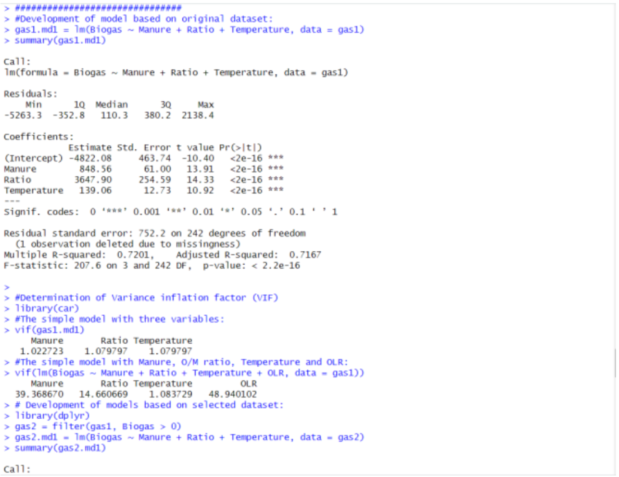
```
Call:
lm(formula = Biogas ~ Manure + Ratio + Temperature, data = gas2)

Residuals:
     Min       1Q   Median       3Q      Max 
-1433.62  -230.23    51.38   222.88  1838.49 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) -3837.751    264.501  -14.51   <2e-16 ***
Manure        972.884     34.736   28.01   <2e-16 ***
Ratio        4481.560    147.083   30.47   <2e-16 ***
Temperature    99.098      7.354   13.47   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 420.3 on 237 degrees of freedom
Multiple R-squared:  0.9027,	Adjusted R-squared:  0.9015 
F-statistic: 732.8 on 3 and 237 DF,  p-value: < 2.2e-16

> #The second and third-order models:
> gas2.md3 = lm(Biogas ~ Manure + Ratio + Temperature + I(Manure^2) + I(Ratio^2) + I(Temperature^2) + Manure*Rati
o*Temperature, data = gas2)
> summary(gas2.md3)

Call:
lm(formula = Biogas ~ Manure + Ratio + Temperature + I(Manure^2) + 
    I(Ratio^2) + I(Temperature^2) + Manure * Ratio * Temperature, 
    data = gas2)

Residuals:
     Min       1Q   Median       3Q      Max 
-1223.22   -93.55     3.88   119.88  1145.99 

Coefficients:

                          Estimate Std. Error t value Pr(>|t|)    
(Intercept)              -4265.463   1957.119  -2.179  0.03031 *  
Manure                     576.750    330.539   1.745  0.08234 .  
Ratio                     7973.188   3827.445   2.083  0.03834 *  
Temperature                215.762    105.103   2.053  0.04122 *  
I(Manure^2)               -265.715     35.813  -7.419 2.26e-12 ***
I(Ratio^2)               -1008.368    597.580  -1.687  0.09288 .  
I(Temperature^2)            -3.953      1.494  -2.646  0.00871 ** 
```



```
Manure:Ratio              -3.565e+03  1.367e+03  -2.607  0.00972 ** 
Manure:Temperature         4.761e+01  7.172e+00   6.638 2.26e-10 ***
Ratio:Temperature         -1.745e+02  1.016e+02  -1.717  0.08725 .  
Manure:Ratio:Temperature   1.265e+02  3.600e+01   3.515  0.00053 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 248.4 on 230 degrees of freedom
Multiple R-squared:  0.967,	Adjusted R-squared:  0.9656 
F-statistic: 674.3 on 10 and 230 DF,  p-value: < 2.2e-16

> #Comparison of the second and third-order models:
> anova(gas2.md3,gas2.md4)
Analysis of Variance Table

Model 1: Biogas ~ Manure + Ratio + Temperature + I(Manure^2) + I(Ratio^2) + 
    I(Temperature^2) + Manure * Ratio * Temperature
Model 2: Biogas ~ Manure + Ratio + Temperature + I(Manure^3) + I(Ratio^3) + 
    I(Temperature^3) + Manure * Ratio * Temperature
  Res.Df      RSS Df   Sum of Sq F Pr(>F)
1    230 14189834                         
2    230 14189834  0 -7.4506e-09          
```

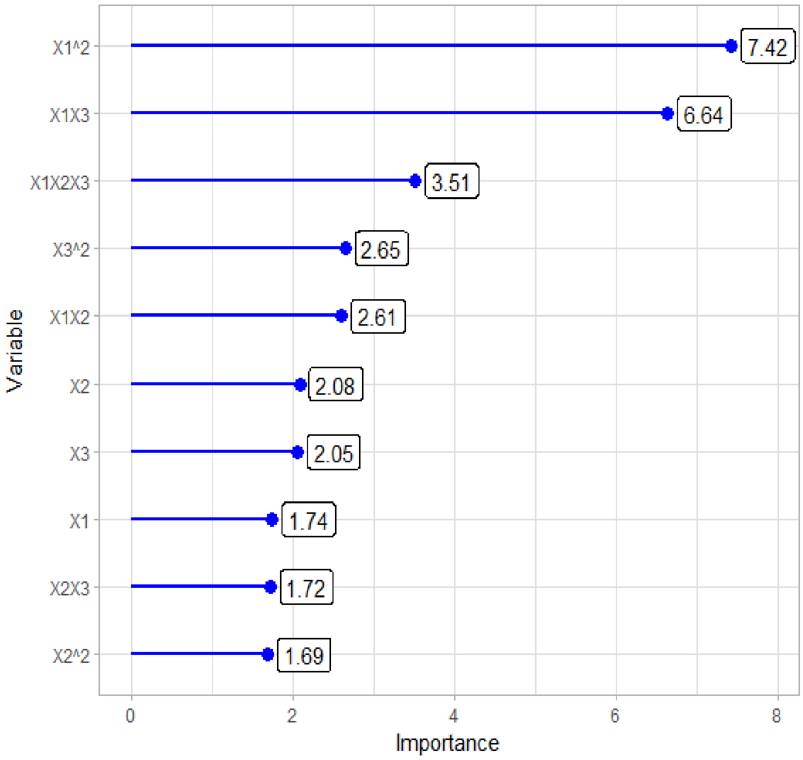


```
Coefficients:
                          Estimate Std. Error t value Pr(>|t|)    
(Intercept)              -4265.463   1957.119  -2.179  0.03031 *  
Manure                     576.750    330.539   1.745  0.08234 .  
Ratio                     7973.188   3827.445   2.083  0.03834 *  
Temperature                215.762    105.103   2.053  0.04122 *  
I(Manure^2)               -265.715     35.813  -7.419 2.26e-12 ***
I(Ratio^2)               -1008.368    597.580  -1.687  0.09288 .  
I(Temperature^2)            -3.953      1.494  -2.646  0.00871 ** 
Manure:Ratio             -3565.278   1367.367  -2.607  0.00972 ** 
Manure:Temperature          47.611      7.172   6.638 2.26e-10 ***
Ratio:Temperature         -174.484    101.598  -1.717  0.08725 .  
Manure:Ratio:Temperature   126.533     35.998   3.515  0.00053 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 248.4 on 230 degrees of freedom
Multiple R-squared:  0.967,	Adjusted R-squared:  0.9656 
F-statistic: 674.3 on 10 and 230 DF,  p-value: < 2.2e-16

> gas2.md4 = lm(Biogas ~ Manure + Ratio + Temperature + I(Manure^3) + I(Ratio^3) + I(Temperature^3) + Manure*Rati
o*Temperature, data = gas2)
> summary(gas2.md4)

Call:
lm(formula = Biogas ~ Manure + Ratio + Temperature + I(Manure^3) + 
    I(Ratio^3) + I(Temperature^3) + Manure * Ratio * Temperature, 
    data = gas2)

Residuals:
     Min       1Q   Median       3Q      Max 
-1223.22   -93.55     3.88   119.88  1145.99 

Coefficients:
                          Estimate Std. Error t value Pr(>|t|)    
(Intercept)              -1.976e+03  1.416e+03  -1.395  0.16427    
Manure                   -1.909e+02  2.761e+02  -0.691  0.49004    
Ratio                     7.805e+03  3.818e+03   2.044  0.04207 *  
Temperature               7.836e+01  5.545e+01   1.413  0.15895    
I(Manure^3)              -2.952e+01  3.979e+00  -7.419 2.26e-12 ***
I(Ratio^3)               -1.344e+03  7.968e+02  -1.687  0.09288 .  
I(Temperature^3)         -3.764e-02  1.423e-02  -2.646  0.00871 ** 
Manure:Ratio             -3.565e+03  1.367e+03  -2.607  0.00972 ** 
```

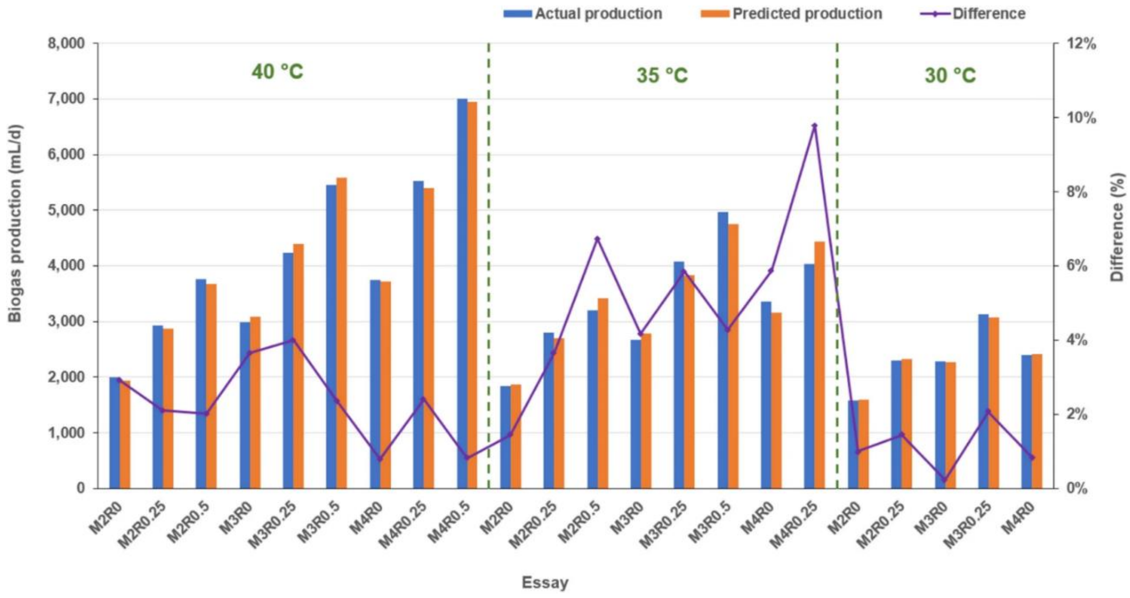


```
> #################################
> #Development of model based on original dataset:
> gas1.md1 = lm(Biogas ~ Manure + Ratio + Temperature, data = gas1)
> summary(gas1.md1)

Call:
lm(formula = Biogas ~ Manure + Ratio + Temperature, data = gas1)

Residuals:
    Min      1Q  Median      3Q     Max
-5263.3  -352.8   110.3   380.2  2138.4

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -4822.08     463.74  -10.40   <2e-16 ***
Manure        848.56      61.00   13.91   <2e-16 ***
Ratio        3647.90     254.59   14.33   <2e-16 ***
Temperature   139.06      12.73   10.92   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 752.2 on 242 degrees of freedom
  (1 observation deleted due to missingness)
Multiple R-squared:  0.7201,    Adjusted R-squared:  0.7167
F-statistic: 207.6 on 3 and 242 DF,  p-value: < 2.2e-16

>
> #Determination of Variance inflation factor (VIF)
> library(car)
> #The simple model with three variables:
> vif(gas1.md1)
     Manure       Ratio Temperature
   1.022723    1.079797    1.079797
> #The simple model with Manure, O/M ratio, Temperature and OLR:
> vif(lm(Biogas ~ Manure + Ratio + Temperature + OLR, data = gas1))
     Manure       Ratio Temperature         OLR
  39.368670   14.660669    1.083729   48.940102
> # Development of models based on selected dataset:
> library(dplyr)
> gas2 = filter(gas1, Biogas > 0)
> gas2.md1 = lm(Biogas ~ Manure + Ratio + Temperature, data = gas2)
> summary(gas2.md1)

Call:
```

#Determination of variable importance:
library(caret)
Imp = as.data.frame(var Imp (gas2.md3))
Imp = data.frame (Variable = c("X1" , "X2" , "X3" , "X1^2" , "X2^2" , "X3^2" , "X1X2" , "X1X3" , "X2X3" , "X1X2X3") , Importance = Imp$Overall) Imp ggplot(Imp , aes(x=reorder(Variable , Importance), y=Importance)) + geom_point (color="Blue", size = 3) +
geom_segment (aes (x = Variable , xend = Variable , y = 0 , yend = Importance), color='Blue', size=1) + labs(x="Variable", y="Importance")+ coord_flip() + theme_light() + geom_label(aes(Variable, Importance , label = signif(round(Importance, digits = 2))), nudge_y = 0.45, size = 4)



#Determination of mean absolute percentage error (MAPE):
library(ie2misc) mape(predict(gas2.md1, gas2), gas2$Biogas, na.rm = FALSE) mape(predict(gas2.md3, gas2), gas2$Biogas, na.rm = FALSE)



RESULT

Using a model built for farm applications, the program was created as a decision support tool to estimate biogas production depending on SM and WKO load and temperature. Before constructing AD systems, it can be utilized to provide advice on digester volume, oil loading, and water usage. For instance, the daily VS output would be 3750 kg-VS/m3/day if the SM production was 15 m3/day and the VSSM was 25.0%. In this situation, a 70%-capacity digester that is comparable in size to a conventional mixed digester56, measuring between 1339 and 2679 m3 or 47,286 and 94,608 ft3, is advised. It is significant to note that the results of the experimental setup and the particular raw materials depend on the very straightforward model and its recommendations.

Conclusion

In conclusion, the role of logistics in renewable energy and sustainability is critical for achieving a greener and more sustainable future. Through the case studies, it is evident that optimized logistics strategies, collaboration among stakeholders, technological innovations, and supportive policies are key drivers of success in renewable energy logistics. However, challenges such as complex project coordination, infrastructure requirements, regulatory compliance, and risk management need to be effectively addressed.

Looking ahead, the future of renewable energy logistics holds immense potential. Emerging technologies and innovations, along with supportive policies and funding opportunities, will play a crucial role in driving the industry forward. By embracing sustainable practices, investing in infrastructure and technology, and fostering collaboration, the logistics sector can contribute significantly to the global transition towards renewable energy and sustainability.

The future of used cooking oil as biodiesel looks promising and holds significant promise for a greener, cleaner, and more sustainable energy future. By harnessing the potential of this waste resource, we can contribute to mitigating climate change, reducing waste, fostering energy security, and creating a more sustainable world for generations to come.

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