NUML Journal of Economics (NJE)

Volume 2, Number 1, June 2025, PP. 1-31
DOI: *https*://doi.org/10.52015/numljournalofeconomics.v2i1.42

# Integrating Shale Gas Development and Hydroponic Farming: A Sustainable Pathway for Energy and Food Security in Pakistan

Atif Ur Rahman[1] Talha Javed[2]

**Article History:**

**Received Date:**
**21st April**

**Revised Date:**
**20th June 2025**

**Accepted Date:**
**28th June 2025**

**Published:**
**30th June 2025**

**Funding**

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

**Abstract**

Pakistan is facing a deep energy crisis primarily a severe energy deficit, which has threatening signs for the Pakistani economy. To that end, this research paper explores whether shale gas development may be the solution to this crisis as it strives to improve food security through hydroponic farming. In the first part, the study entails an implication of the exploration potential of shale formations in Pakistan, especially with regard to porosity, thickness and depth implications on the rate of gas flow and drilling expenses. Consequently, the results suggest that Pakistan's shale gas resources contain about 105 trillion cubic feet, which represents significant potential for production.

Besides the assessment of the effectiveness of modern technical approaches to the development of the technology for shale gas extraction, the study focuses on the global trends for the implementation of shale gas development with an emphasis on hydraulic fracturing technology. It also covers issues of the environmental impact of the extraction techniques and measures on how these can be reversed to enhance sustainable practices for the environment. The economic viability of shale gas is determined by the evaluation of initial costs involved and secondly, the strength of its economic returns for the national economy in the long run.

In addition, the paper goes further to demonstrate the practice of hydroponic farming as a sustainable farm practice that can help reduce water usage while at the same time increasing crop production. This research promotes cross-sector cooperation with the energy and agriculture industries disclosing local opportunities to meet critical challenges in energy and food security. In the long run, strong and effective government policies regarding shale gas drilling and hydroponic farming projects would indeed help in the creation of a stronger economy in Pakistan for accommodating its increasing needs.

**Keywords :-** Hydroponics, Shale Gas, Sustainability, Energy Crisis, Food Security, Economic Viability

[1] Department of Chemical Engineering, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi 23640, Pakistan; atifups7@gmail.com

[2] Department of Chemical Engineering, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi 23640, Pakistan; javedtalha649@gmail.com

## Introduction

Pakistan is an agricultural country with the labor force of around 42.3% working directly in the agricultural sector contributing 18.9% of the state GDP from only 28.05% of the area under cultivation. Pakistan, born in a farm, has felt the spirit of agriculture vanishing largely due to the lack of water, deteriorating soil quality and moreover increasing food requirements. The demand to provide nutrition for a growing population has become even higher, prompting innovation aimed at feeding the world affordably and sustainably. Conventional farming practices which largely depend on soils and water to support agriculture have been unable to address these emerging challenges, hence the need to develop new sustainable strategies that can increase yields while at the same time conserving the limited soil and water resources (Ingrao et al., 2023)**.**

In an effort to meet these challenges one area of optimism is the development of shale gas resources. Fracking, or hydraulic fracturing, has turned into an essential technology used in shale gas production processes to affect the global energy markets. Shale gas identified by the United States as a clean energy source may provide Pakistan with an opportunity to develop other energy sources apart from conventional fossil fuels. On the basis of the prospective sources of energy, shale gas was found to have the potential to enhance the energy security of the country in question while augmenting economic development (*AFDC 2014*, n.d.) (*Boyer C*, n.d.). Shale gas resources could be explored and developed to help remove the energy deficit that is a major challenge to increased agricultural yields and industrialization (*Cipolla Cl*, n.d.)(*EIA 2013*, n.d.)**.**

The rocks in Pakistan show some signs of the exploitable potential of its shale gas resource (*EIA 2011*, n.d.). But, the problems of negative environmental effects in the course of hydraulic fracturing and the legal requirements have to be taken into consideration for further sustainable development (Energy Information Administration, 2014)**.** The profitability of shale gas also creates the potential possibility of making Pakistan a regional hub of energy production and cutting down the vulnerability of the country to imported oil by enhancing the internal exploitable fields (Key Results from AEO2015 2, n.d.) (*EIA 2016*, n.d.)**.**With the energy problems that exist in the country and arising from inadequate energy to support the agriculture business, shale gas could offer the boost needed for the agriculture sector.

Similar to energy trends, agriculture faces new challenges such as water and soil scarcity and has to respond with new developments. With a proper nutrient solution, hydroponics which is the process of agriculture without the use of soil has become an alternative method of farming. This protective measure of farming in that it does not directly come into contact with the soil has the added advantage of being able to produce crops all through the year and thus increase food production(*Bradely*, n.d.)(Role of Hydroponics in Improving Water-Use Efficiency and Food Security, n.d.) **.** Hydroponics is gaining popularity all over the world as countries look for ways of improving agriculture in the face of climate change and increasing urbanization. The studies reveal that the hydroponics system can produce crops more productively as compared to the conventional techniques; the water conservation per study ranged between 50 to 70 percent (*Oztekin*, n.d.) (Ravindra B. Malabadi et al., 2024)**.**

This paper aims to argue that methods of growing plants in nutrified water or any other medium excluding soil have a lot of advantages over the traditional soil-based farming. These methods consist of aeroponic growth, aquaponic, and other solid media cultures, all meant to minimize resource waste and at the same time maximize production potential(*Guo C,* n.d.-a) **.** The above-mentioned practices ultimately allow the farmers to double or triple their yields and at the same time, improve the quality of food. Furthermore, the best practice of soil-less farming would solve the problems of malnutrition and food insecurity in the world on one hand and at the same time create wealth for the farming populace.

Expanding the focus of this study reaffirms the need to detail the particular strengths and weaknesses of each type of soil-less farming technique. As these methods apply, it is important to advance their effectiveness alongside the scale-up process to warrant further research and development. Therefore, further expansion of the areas under SMF and its sustainability depends on cooperation between all interested parties: scientists, lawmakers, and producers.

The global population is growing at a rate of 1 person per year per 100 people therefore creating more demand on many of the earth's natural resources including food production. Farm-based farming needs to intensify so as to feed the increasing population(Fleck et al., 2012) **.** As the name from 'hydro' meaning water and 'pones' having to do with suffering hydroponics is a technique for enhancing vegetative production other than in soil(Nguyen et al., 2022) **.** Hydroponics is a system of growing plants in nutrient solutions without soil, bears relation to a bigger category referred to as hydroculture.

Farming has an estimated worth of USD 5 trillion worldwide and according to (Pavlovic et al., 2021)**,** projections agreed that demand would reach an incredible, 70% by 2050. Thus, hydroponics seems to be on the list of the primary directions for meeting human demand for food in the future and for searching for perspectives on feeding the world in the framework of environmental safety.

Hydroponics is rapidly emerging in some regions, and right now Europe leads in the market with a 37% stake of the global market. This has been made possible by the large-scale mushroom greenhouse agriculture that has become popular in countries for example France and the Netherlands, which engage in advanced growing techniques particularly relevant for the climate-controlled system(Baloch et al., 2017)**.** The introduction of new forms of hydroponics or commercial vertical indoor farms in areas such as the Gulf Cooperation Council (GCC) is evidence of how the technology maybe optimally used in addressing local produce demands while putting into consideration the impacts of the existing horticultural systems.

Modern civilization has only just discovered the concept of hydroponics even though ancient society had been using it for ages The present generation of farmers is only investigating the usefulness of hydroponics in light of future food scarcity. The current valuation of the food and agribusiness sector is expected to surge owing to growing demand around the world(Ravindra B. Malabadi et al., 2024). For example, Vertical farming such as the one by Badia Farms in UAE captures this idea well by adopting hydroponics to grow pesticide-free vegetables indoors through inventive vertical farming techniques(Fleck et al., 2012) **.**

In sum, this research paper seeks to try and gain a better understanding of the feasibility of hydroponics, coupled with the advantages of establishing shale gas or not in the context of Pakistan. Thus, this study aims to shed light on the diverse opportunities associated with shale gas development and hydroponic farming, together with their potential impact on the revolution of agricultural practices and sustainable food production systems in Pakistan, based on a patterned and inclusive cost-benefit analysis complemented by the identification of inherent difficulties in both sectors.

When dealing with these matters concerning energy security and food sustainability, it is crucial to notice that Pakistan is a country that suffers from resource scarcity. As we go through the details of addressing several matters within the context of this country, it becomes rather important to take cognizance of the fact that there are now multifaceted problems that any member of the society faces.

## Literature Review

Shale gas development and hydroponic farming present a bona fide analysis of energy demand in the current society, current technological developments, and sustainable farming. This paper reviews the literature on both energy and food security with particular focus on the application of these literatures in the context of the energy crisis and food security in Pakistan.

### Shale Gas Development

The structure of the system for producing energy sources in the modern world is changing, and shale gas has become an important focus. Shale gas is natural gas which exists in shale rock and has the features of low permeability and low porosity. This resource has become economically recoverable due to the development of hydraulic fracturing and horizontal drilling technologies. Actually, the US has recently become the world leader in shale gas production, and the EIA's prediction for 2015/2040 is that the latter will amount to 30 Tcf for the US, which will be a great contribution to the global energy supplies.

Currently, Pakistan has positioned itself among the top ten countries in terms of RR which is estimated at 9 billion barrels of shale oil and 105 trillion cubic feet of shale gas(*EIA 2013*, n.d.) . The resources in Pakistan which include Datta, Hangu, Patala, Ranikot, Sembar, and Lower Goru have the capacities to host shale gas. Research has shown that these structures possess trends comparable to the best-played shales in North America(*Mohyuddin*, n.d.) .

The economic feasibility of developing these resources is contingent upon several factors: the types of formations, technology used in the extraction of the resources, and legal instruments used in the management of the resources. Hydraulic fracturing especially gets involved in releasing shale gas because it provides fractures that assist the flow of the gas (*Guo C*, n.d.-b)**.** But there are environmental issues that accompany the use of hydraulic fracturing including water pollution and triggered earthquakes that require sound regulation of the process to ensure responsible extraction(Esterhuyse et al., 2014) **.**

In Pakistan the demand for natural gas is increasing mainly because of the phenomenon of urbanization and population increase. Natural gas consumption increased from 3.5 billion cubic meters in 2004 to about 4 billion cubic meters in 2014, whereby the graph shows the increasing energy demand of the country(Wainberg et al., 2017) **.** These figures alone explain the need for new energy supplies like shale gas to help fill the supply deficit.

| *Sector* | *Percentage (%)* |
|---|---|
| *Power* | 35.17 |
| *Fertilizer Fuel* | 2.56 |
| *Domestic* | 21.46 |
| *Cement* | 0.03 |
| *Fertilizer(FS)* | 13.52 |
| *Commercial* | 2.15 |
| *Gen-Industry* | 16.97 |
| *Transport* | 4.48 |

*Table 1 : Trends in Natural Gas Production and Consumption in Pakistan*

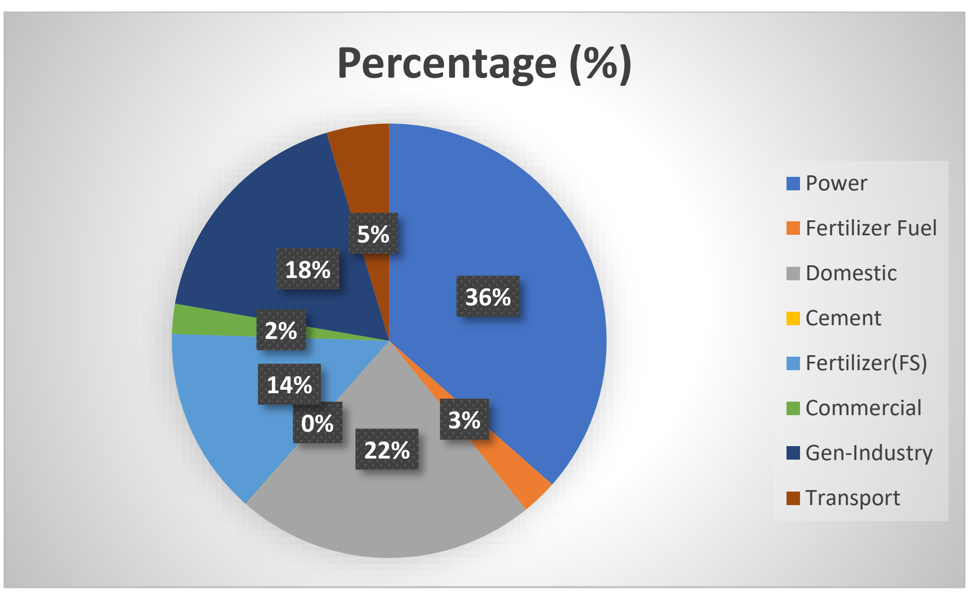



*Figure 1 : Trends in Natural Gas Production and Consumption in Pakistan*

**Hydroponic Farming**

Equally critical to energy issues, the advancements in hydroponic farming have signified its feasibility as a revolutionary concept in the agricultural sector of Pakistan, which has the potential to deal with the problem of food security. Hydroponics is a system of growing plants in nutrient enhanced water solutions and devoid of soil. It is a water saving and annual planting method that makes it suitable for use in areas that experience water rationing.

Studies show that through hydroponics, people can produce crops at a much faster rate than field agriculture. For instance, it has been found that hydroponically grown crops generally have higher growth rates, and possess improved nutritional values with respect to soil grown crops(*Oztekin*, n.d.) (Ravindra B. Malabadi et al., 2024). The opportunity to influence nutrient delivery with high accuracy ensures optimal conditions for plants.

The people's employment of hydroponics is in line with governmental efforts to increase agricultural efficiency through innovative methods. There are new concepts of farming, like hydroponics recommended in the China Pakistan economic Corridor CPEC with an aim of boosting high value crops. Though hydroponic systems require higher initial investment, the cost implications for water usage and enhanced crop productivity make them desirable especially among farmers operating under resource shortages.

| Method | Yield | Simplicity | Cost | Pros | Cons |
|---|---|---|---|---|---|
| Kratky | Moderate | High | Low | Gentle introduction to hydroponics<br>Low-maintenance, passive system<br>No moving parts | Slower plant growth |
| Deep Water Culture (DWC) | Moderate | High | Moderate | Easy to maintain and set up<br>Relatively low cost<br>Ideal for beginners | Sensitive to air pump failures, leading to root rot |
| Vertical Grow Tower (NFT) | Moderate | Low | Moderate | Space-efficient<br>Relatively easy to DIY | Requires technical expertise<br>Can be expensive to set up |
| Ebb & Flow | Moderate | Moderate | Moderate | Easier to maintain than NFT systems<br>Suitable for beginners | Prone to nutrient solution imbalances<br>Requires careful monitoring |
| Nutrient Film Technique (NFT) | High | Moderate | Moderate | High yield potential<br>Efficient nutrient delivery | Requires precise control of nutrient solution flow<br>Sensitive to pump failures |

*Table 2 : Comparison of Hydroponic Systems*

In addition, hydroponic systems may be designed to include renewable energy sources such as solar energy, to enhance the feasibility of hydroponic systems(Fleck et al., 2012) . With technology integration and eco-friendly methods, hydroponics outlines itself as a means to feed the growing population without adversely affecting the natural world.

### The Combination of Shale Gas Development with Hydroponically Cultivated Aquaculture

Shale gas development and hydroponic farming are closely related subjects that can help Pakistan resolve its energy crisis as well as its issues concerning food production. The possibility of using shale gas as an energy resource to support production as a clean energy resource can offer the power required to run hydroponic systems effectively. It means that Pakistan can diversify the utilization of local energy sources, which can decrease dependence on imported oil and fuel and improve agricultural yield.

Furthermore, finances realized from shale gas could be channeled towards improving emerging agricultural technologies like hydroponics. This mutual partnership may contribute to sustainable development since it will create employment opportunities in both sectors and at the same time enhance the preservation of environmental assets.

The literature reveals that shale gas development and hydroponic farming can offer prospects for meeting both energy and food security challenges in Pakistan. Moreover, the establishment of innovative technologies and sustainability in both sectors will serve as a pattern for Pakistan to transform the face towards a more secure future in meeting the growing population, as well as preserving natural resources.

## Materials and Methods

It includes details of the materials as well as the methods used in the projects related to shale gas development and hydroponic farming in Pakistan. Thus, each project uses special elements and approaches compatible with its aims and goals.

### Solutions for hydroponic farming

#### Reservoir:

The hydroponic system uses a Deep Water Culture (DWC) type of model reservoir which has dimensions of 13.5” × 8.25” × 8.3”. It is covered with aluminum foil to control temperature and to reduce the growth of certain microorganisms.

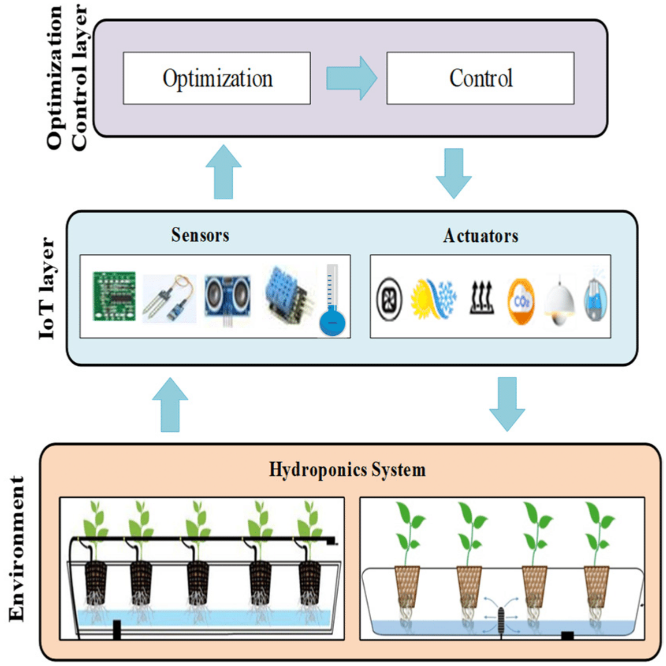



*Figure 2 : Deep Water Culture Reservoir System(Khudoyberdiev et al., 2020)*

**Net Pots:**

Net pots with a meshed base are used as the plants roots can penetrate through the base to access the nutrient solution. These pots contain expandable clay pellets which form the framework of plant support and act as a medium that supports air circulation.

**Oxygen Supply System:**

An air pump for aeration via a silicone pipe is used to deliver oxygen to the nutrient solution through a porous air stone to provide uniform aeration required for healthy root growth.

**Grow Lights:**

To cater to the needs of plants during their growth in areas where sunlight may not be easily available, full spectrum LED grow lights having IP65 waterproofing capability are used.

*Figure 3 : Grow Lights for Hydroponics (Ai Generated)*

**Nutrient Solution:**

Flora Gro, Flora Micro, and Flora Bloom, are used to prepare a fertilizer solution that is applied to cater to the plants nutritional requirements during different development cycles.

**Climate Control Equipment:**

In some cases, a number of equipment such as fans or heaters may be required in order to keep the interior environment of the growing system at an optimal condition.

**Water Quality Testing Equipment:**

Nutrient solution qualifies for plant growth, and pH and electrical conductivity (EC) level indicators are employed for testing.

**Miscellaneous Supplies:**

They include accessory measuring instruments like a planimeter, measuring tape and Vernier caliper for ecological variables assessment within plant growth parameters and others such as cleaning items for general system sanitation.

**Experimental Design**

The survey was administered in the Department Laboratory of Farm Structures, Faculty of Agricultural Engineering between September and November 2019. Spinach seeds were started in foldable plastic germination trays containing coco coir as the growing media and later transferred to the hydroponic system for continued production.

**Physiochemical Properties of Nutrient Solution:**

Other factors including, ambient temperature, electrical conductivity (EC), total dissolved solids (TDS), pH and water temperature were maintained and recorded at three-day intervals during the entire period of the experiment.

**Plant Growth Analysis:**

Evaluation of growth parameters of spinach plant: A study on selected crops under hydroponic and traditional conditions Growth rates, including area expansion, height development, and increase in stem thickness were determined for a sample of spinach crops grown hydroponically and in traditional fashion.

Other parameters such as leaf area, plant height, and stem diameter were collected by a planimeter, measuring tape, and Vernier caliper, respectively.

**Water Quality:**

Filtered water with a certain electrical conductivity, TDS and pH was used here as a hydroponic model solution compared to the irrigation water which is otherwise used for conventional cultivation.

**Cost Estimation of Hydroponic Model:**

The overall cost of the hydroponic system was obtained from the addition of unit costs of all the materials used in its construction and planning.

**Fertigation Techniques:**

The fertigation strategies involved delivering the nutrients efficiently to the plants without significant wastage of resources.

**Potential hazardous materials associated with shale gas development**

**Drilling Equipment:**

Specific drilling platforms that can drill to substantial shale deposits can be utilized in the production of shale gas.

**Hydraulic Fracturing Fluids:**

Fluid involves water and sand and chemicals is pumped into the shale rocks at high pressure to create cracks that improve the flow of natural gas(*AFDC 2014*, n.d.) **.**

**Pipelines:**

There is a need for transportation of extracted shale gas from the production area to the processing center.

**Monitoring Systems:**

Highly advanced monitoring equipment is used to control and record pressure, temperature and the flow rate when drilling and during the fracturing process.

**Environmental Monitoring Tools:**

Monitoring equipment for air quality, water pollution and shocks plays have a crucial role in evaluating the effects of shale…

**Regulatory Compliance Materials:**

To meet local legislation documents that promote environmental management, responsible extraction practices are attained(*Guo C*, n.d.-b) **.**

The above stated materials and methods appear to contain all that is required to study both shale gas development in Pakistan and hydroponic farming. Thus, through understanding innovative technologies and sustainable practices implemented in both sectors this research intends to make a valuable contribution towards the task of solving the energy crisis and food insecurity in Pakistan.

## Methodology

### 1. Research Design

This research work uses survey, observation, and interview approaches as a part of an explorative study to analyze the possibilities of shale gas development and hydroponic farming system in Pakistan. The research design includes:

Literature Review: Analyzing a vast set of research material, articles, conventional and social media resources on Shale oil/gas reserves and Production mechanisms, Hydroponics/ Hydroponic farming internationally and in Pakistan. Specifically, this review helps to bridge the existing knowledge gap and define the research framework.

### 2. Data Collection

Geological Data: Information on the shale resources, their geological characteristics, and exploration potential in Pakistan was obtained from government reports, academic literature, and industry studies. Modeling of important parameters like porosity, thickness and depth of shale formation was made.

Economic Data: The economic viability was assessed based on consideration of the previous economic reports; estimate cost to extract shale gas and the estimated market price of the natural gas. Information in hydroponic farming costs and yield was also obtained from various agricultural research studies.

Environmental Impact Studies: Professional and academic literature on the results of shale gas and hydroponic farming were used to evaluate environmental reports. This ranges from research on water resources, soil quality and the effects on the atmosphere including emissions of gas.

**3. Analytical Techniques**

Statistical Analysis: Quantitative data were subjected to statistical tests in order to test hypotheses relating to relations between shale gas production potential and economic recoverability. This included regression analysis in order to forecast future production patterns after analyzing the past data.

Comparative Analysis: A synthesis with the subject of the shale gas development in the context of the success stories from the other countries such as United States, Canada and China was conducted. In this analysis, technological progress, laws, and norms, as well as economic factors were at the center.

**4. Case Studies**

Hydroponic Farming Implementation: Field surveys were also employed to identify existing hydroponic farms in Pakistan in order to assess their performance in terms of efficiency, yield and economic profitability. Hearing from farmers within hydroponic systems and other stakeholders allowed for the collection of qualitative data regarding the issues and benefits of hydroponic farming systems.

**5. Synthesis of Findings**

The collected data from geological surveys, economic calculations, environmental impacts studies, and case studies were used to present an integrated perspective of the viability of synchronizing shale gas extraction with hydroponic farming in the selected regions of Pakistan.

This research method ensures that shale gas development and hydroponic farming are studied with reference to their relationship in Pakistan effectively. Using both qualitative data and quantitative analysis, the study integrates both qualitative findings and quantitative data to make a positive contribution to knowledge in the area of energy security and sustainable agriculture.

## Results

This section gives the findings from the hydroponic farming business as well as the shale gas development business. The findings section of each project is presented with appropriate figures and tables as appropriate for the data analyzed.

### Hydroponic Farming Results

**Physiochemical Properties of Nutrient Solution:**

During the conduct of the experiment, essential physicochemical factors including ambient temperature, electrical conductivity, total dissolved solids, pH and water temperature were closely monitored. Information collected every three days is presented in the table 3 below**.**

| S. No | Application interval (Weeks) | Flora micro (ml) | Flora gro (ml) | Flora bloom (ml) | water applied (litre) |
|---|---|---|---|---|---|
| **1** | 1st | 10 | 10 | 5 | **8** |
| **2** | 2nd | 8 | 8 | 8 | **8** |
| **3** | 3rd | 8 | 2 | 10 | **8** |
| **Total** | **3** | **26** | **20** | **23** | **24** |

*Table 3 : Physiochemical Properties of Nutrient Solution*

**Plant Growth Analysis:**

Some of the over essential parameters concerning the growth of spinach crops under hydroponic system were compared with conventional practice. The findings revealed highly significant differences in the growth parameters as described in figure 4 ,5,6**.**

**Growth Comparison of Hydroponically Grown vs. Traditionally Grown Spinach**

*Table 4:Plant Height*

| System | Sample-1 | Sample-2 | Sample-3 | Sample-4 | Sample-5 |
|---|---|---|---|---|---|
| **Hydroponic-1** | 21.6 | 23.5 | 21.9 | 20.9 | 22.5 |
| **Hydroponic-2** | 23.1 | 21.6 | 20.6 | 23.3 | 21.5 |
| **Geoponic-1** | 16.5 | 17.8 | 16.7 | 15.7 | 16.4 |
| **Geoponic-2** | 15.5 | 17.2 | 16.4 | 15.3 | 16.4 |

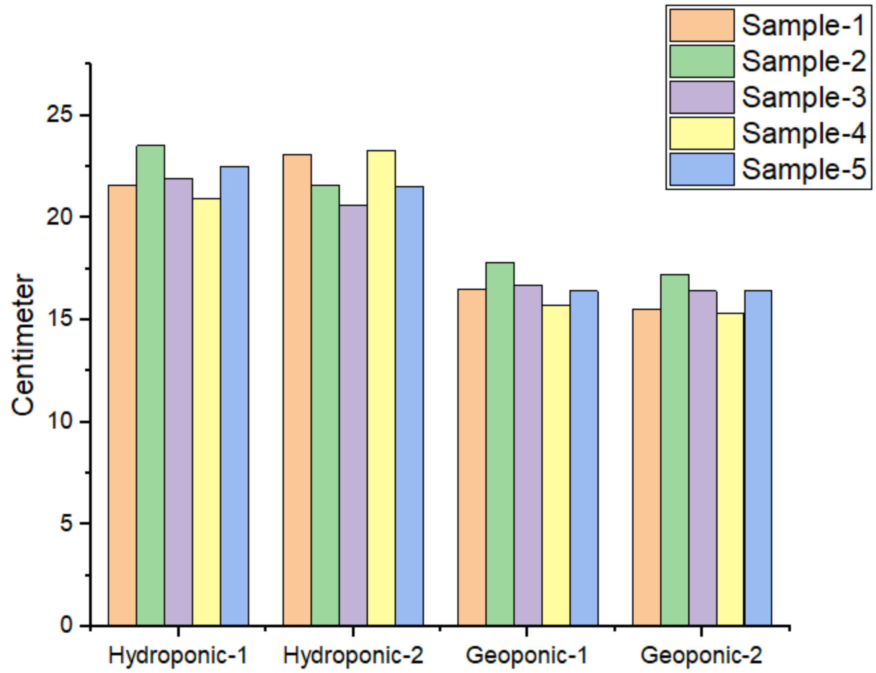



*Figure 4 :Plant Height*

*Table 5 :Plant Stem Size*

| **Plant Type** | **Sample 1** | **Sample 2** | **Sample 3** | **Sample 4** | **Sample 5** |
|---|---|---|---|---|---|
| **Hydroponic 1** | 0.14 | 0.18 | 0.16 | 0.13 | 0.17 |
| **Hydroponic 2** | 0.14 | 0.18 | 0.16 | 0.13 | 0.17 |
| **Geoponic 1** | 0.11 | 0.14 | 0.12 | 0.1 | 0.13 |
| **Geoponic 2** | 0.1 | 0.13 | 0.11 | 0.1 | 0.12 |

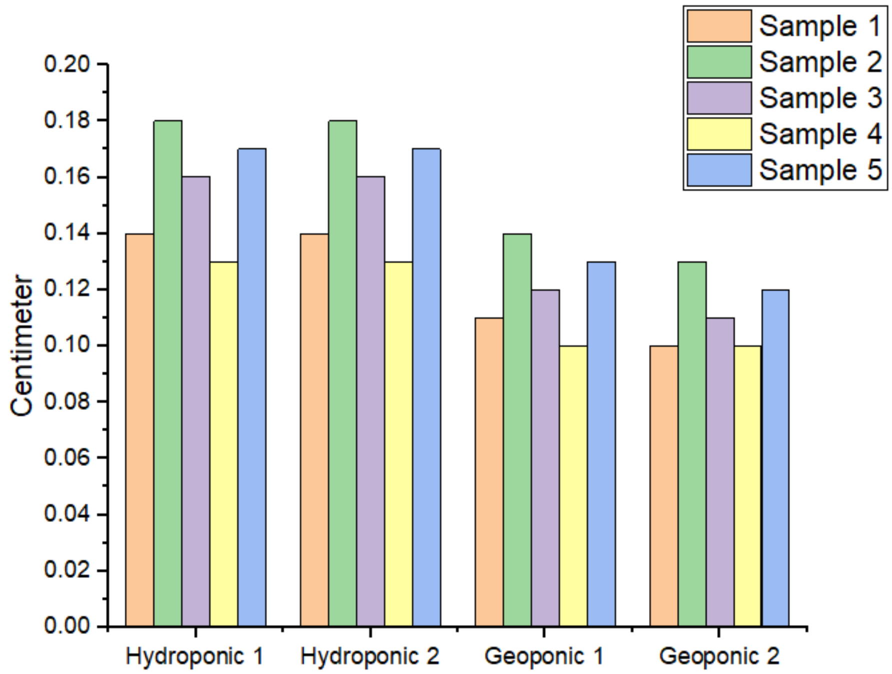



*Figure 5 :Plant Stem Size*

*Table 6 :Plant Leaf Area*

| System | Sample-1 | Sample-2 | Sample-3 | Sample-4 | Sample-5 |
|---|---|---|---|---|---|
| **Hydroponic-1** | 1.17 | 2.25 | 2.22 | 2.01 | 2.21 |
| **Hydroponic-2** | 1.17 | 2.18 | 1.96 | 2.17 | 2.21 |
| **Geoponic-1** | 0.95 | 1.69 | 1.71 | 1.51 | 1.66 |
| **Geoponic-2** | 0.93 | 1.67 | 1.5 | 1.61 | 1.64 |

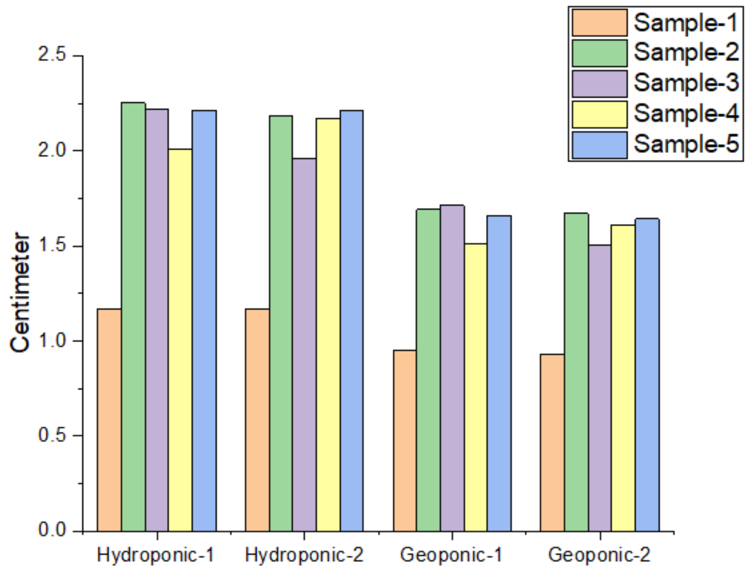



*Figure 6 :Plant Leaf Area*

**Water Quality Assessment:**

Hydroponic system used allowed monitoring of the quality of water used for the growth of the plant. These are presented in the following table, specifically Table 7.

*Table 7:Water Quality Parameters*

| S. No | EC (µS/cm) | TDS (ppm) | pH | EC (µS/cm) | TDS (ppm) | pH | Growth duration (Days) |
|---|---|---|---|---|---|---|---|
| | Reservoir 1 | | | Reservoir 2 | | | |
| 1 | 1508 | 754 | 5.6 | 1422 | 711 | 6.1 | 1st |
| 2 | 1950 | 975 | 6.4 | 1486 | 754 | 5.9 | 3rd |
| 3 | 1698 | 849 | 6.0 | 1756 | 878 | 5.7 | 6th |
| 4 | 1444 | 733 | 5.9 | 1360 | 690 | 6 | 9th |
| 05 | 1402 | 711 | 6.2 | 1292 | 646 | 5.1 | 12th |
| 6 | 1422 | 711 | 5.6 | 1508 | 754 | 6.8 | 15th |
| 7 | 1056 | 528 | 6.5 | 1078 | 539 | 6.4 | 18th |
| 8 | 1250 | 625 | 6.3 | 1219 | 608 | 6.5 | 21st |

**Cost Estimation:**

The cost analysis for developing the hydroponic system revealed that it cost PKR 9680 per unit of the system. This assessment is therefore of great usefulness in determining the economic prospects of hydroponic practices in Pakistan.

*Table 8:Estimated Cost (In PKR) for Hydroponics Setup*

| Items | Cost Range (USD) |
|---|---|
| **Initial Setup (including tanks, pumps, lights, etc.)** | 1500-15M |
| **Nutrient Solutions** | 1000-20M |
| **Seeds** | 1500-30M |
| **Electricity** | 5000-50M |
| **Labor** | 2500-45M |
| **Maintenance** | 1700-30M |
| **Marketing** | 1800-30M |
| **Distribution** | 1250-30M |

## Climate Control Performance:

Urban hydroponic system kept optimum temperature and humidity inside the enclosed structure better than the traditional open field farming. The changes in temperature are also depicted below in Table 9 below.

*Table 9 : Temperature and Relative Humidity Under Hydroponics*

| S. No | Reservoir 1 Inside Temp: (°C) | Reservoir 2 In- side Temp: (°C) | Indoor outside Temp: (°C) | Indoor R.H (%) | Traditional Ambi- ent Temp: (°C) | Outdoo r R.H (%) | Growth Dura- tion (Days) |
|---|---|---|---|---|---|---|---|
| **1** | 28.00 | 28.1 | 28.7 | 50 | 37.0 | 56.0 | **1st** |
| **2** | 28.90 | 28.8 | 29.4 | 44 | 33.0 | 61.0 | **3rd** |
| **3** | 28.60 | 28.4 | 28.3 | 69 | 34.0 | 69.0 | **6th** |
| **4** | 28.40 | 28.4 | 27.6 | 56 | 33.0 | 67.0 | **9th** |
| **5** | 29.10 | 30.4 | 29.4 | 40 | 31.0 | 60.0 | **12th** |
| **6** | 30.00 | 30.2 | 28.8 | 47 | 31.0 | 60.0 | **15th** |
| **7** | 28.20 | 28.4 | 29.1 | 40 | 29.5 | 54.0 | **18th** |
| **8** | **28.10** | **28.1** | **28.7** | **49** | **30.0** | **56.0** | **21st** |

## Fertigation Techniques:

The fertilizer solution applied in this model is a hydroponically grown nutrient and mineral solution for the plants, which comprises Flora grow fertilizer, Flora micro fertilizer, and Flora bloom fertilizer.

**Graphical Representation of Hydroponic Model:**

A plan of the hydroponic model that has been used is presented in Figure 5 which illustrates a protracted view of the model from the top as well as the side.

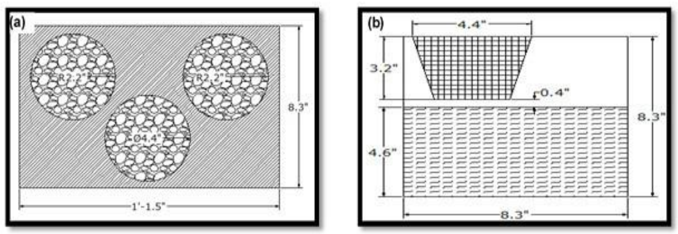



*Figure 7 :Schematic View of Hydroponic Model*

**Market Analysis for Hydroponics:**

A market analysis showing projected growth trends for hydroponics globally is illustrated in Figure 9.

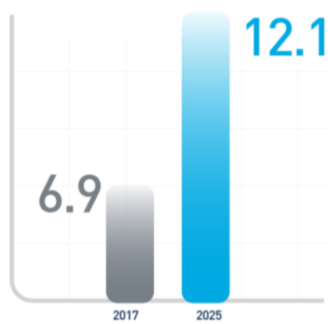



*Figure 8:Estimated Valuation of Global Hydroponics Market [2017-2025]*

**Statistical Analysis of Hydroponics in Pakistan:**

Statistical projections for hydroponics production in Pakistan are summarized in Table 10.

*Table 10 :Projected Growth of Hydroponics Market in Pakistan*

| Year | Market Size (USD Billion) |
| --- | --- |
| 2024 | $5.06 |
| 2029 | $7.36 |

**Economic Viability Assessment:**

A detailed cost-benefit analysis is shown in Table 11, indicating potential returns on investment from hydroponic farming.

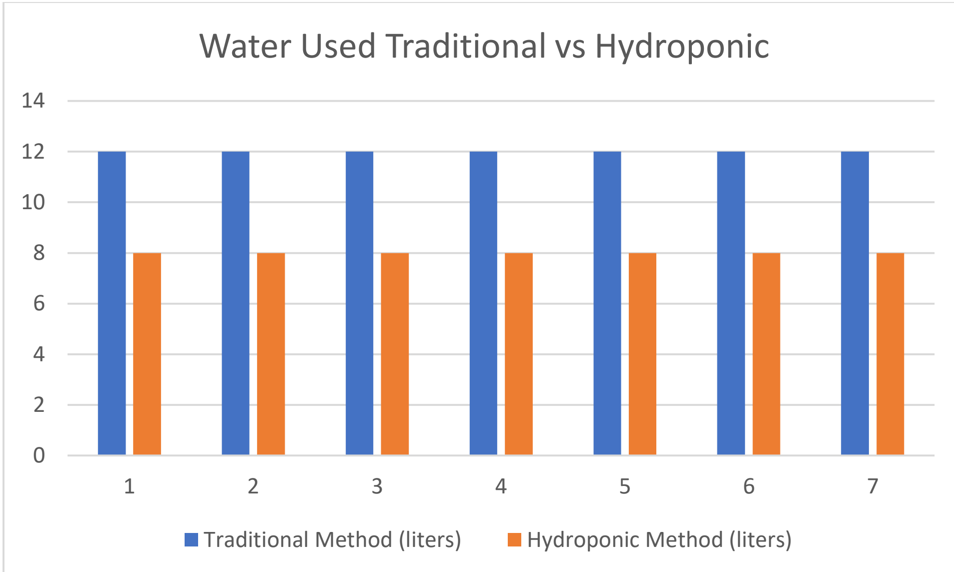
| S. No | Material/Item Name | Price per unit (PKR) | Quantity | Total price (PKR) |
|---|---|---|---|---|
| **01** | **Air Pump** | 450.00 | 01 | **450.00** |
| **02** | **Air Stone** | 100.00 | 01 | **100.00** |
| **03** | **TDS and EC Meter** | 1100.00 | 01 | **1100.00** |
| **04** | **pH Meter** | 1000.00 | 01 | **1000.00** |
| **05** | **Digital temperature and humidity meter** | 850.00 | 01 | **850.00** |
| **06** | **Net Cup** | 50.00 | 03 | **150.00** |
| **07** | **Styrofoam Sheet** | 80.00 | 01 | **80.00** |
| **08** | **Plastic Reservoir** | 400.00 | 01 | **400.00** |
| **09** | **Hydroponic flora grow, bloom micro (120 ml)** | 1000.00 | 01 | **1000.00** |
| **10** | **Full-Spectrum LED Grow Light (100 W)** | 1500.00 | 01 | **1500.00** |
| **11** | **Digital Timer Device** | 1650.00 | 01 | **1650.00** |
| **12** | **Coco Peat** | 100.00 | 01 | **100.00** |
| **13** | **Clay Pebbles** | 200.00 | 01 | **200.00** |
| **14** | **Seedling Tray** | 150.00 | 02 | **300.00** |
| **15** | **Aluminium Foil** | 250.00 | 01 | **250.00** |
| **16** | **Silicone Air and Water Tube** | 100.00 | 01 | **100.00** |
| **17** | **PVC LED Light Mount** | 450.00 | 01 | **450.00** |
| **Total price for hydroponic unit** | | | | **9,680.00** |

Table 11 : Cost-Benefit Analysis of Hydroponic Farming

**Comparative Water Usage Efficiency:**

A comparison of water usage efficiency between traditional farming and hydroponics is illustrated in Figure 10.

*Figure 9 : Water Usage Efficiency Comparison*




**Shale Gas Development Results**

**Geological Assessment:**

The prospective shale gas formations are Datta, Hangu , Patala, Ranikot, Sembar and Lower goru formations. Finally, characteristics of each formation were assessed to draw conclusions on their feasibility of extracting gas.

**Environmental Impact Analysis:**

All the environmental surveillance instruments were used to measure air pollution and potential hazards posed by groundwater pollution from hydraulic fracturing activities. Initial studies showed that the negative effects on other species within the environment were small if the guidelines were implemented.

**Economic Viability Assessment:**

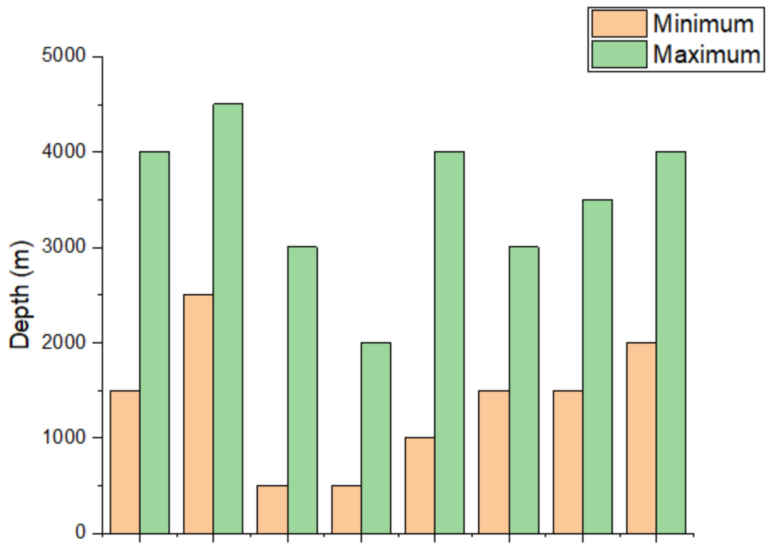
A cost-investment analysis was made to determine the economic profitability of shale gas in Pakistan. Research conclusions reveal that shale gas can support and enhance the energy security status of a country if adequate capital is devoted to technology and development of the equipment necessary for shale drilling.

**Regulatory Compliance Evaluation:**

Lessons from a survey highlight how regulation can be strengthened to better protect the environment in order to further develop the shale gas resource.

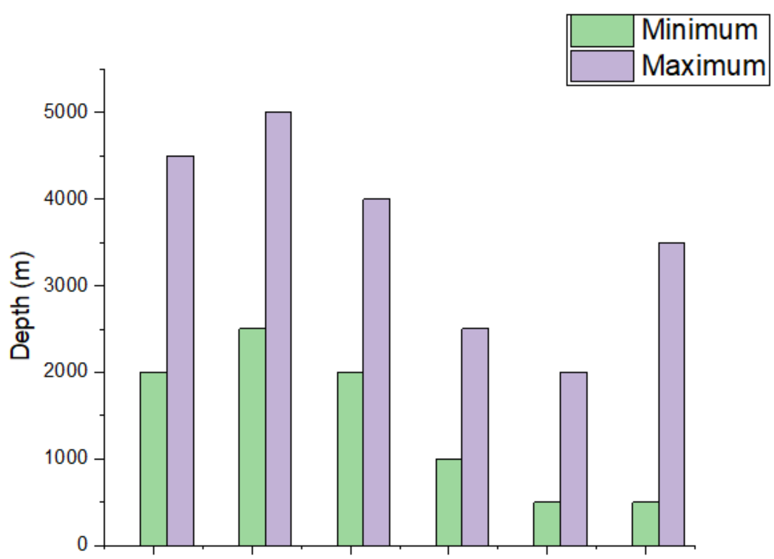
## Average depth of North Korea Shale plays:-

| Shale Play | Region | Minimum Depth (m) | Maximum Depth (m) |
|---|---|---|---|
| **Barnett** | North America | 1500 | 4000 |
| **Haynesville** | North America | 2500 | 4500 |
| **Antrim** | North America | 500 | 3000 |
| **New Albany** | North America | 500 | 2000 |
| **Eagle Ford** | North America | 1000 | 4000 |
| **Fayetteville** | North America | 1500 | 3000 |
| **Montney** | North America | 1500 | 3500 |
| **Duvernay** | North America | 2000 | 4000 |



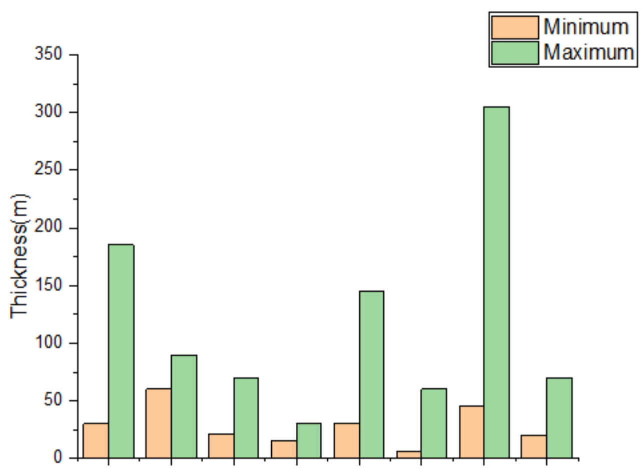

## Average depth of Pakistani shale plays:-

| Shale Play | Region | Minimum Depth (m) | Maximum Depth (m) |
|---|---|---|---|
| Datta | Pakistan | 2000 | 4500 |
| Hangu | Pakistan | 2500 | 5000 |
| Patala | Pakistan | 2000 | 4000 |
| Ranikot | Pakistan | 1000 | 2500 |
| Lower Goru | Pakistan | 500 | 2000 |
| Sembar | Pakistan | 500 | 3500 |



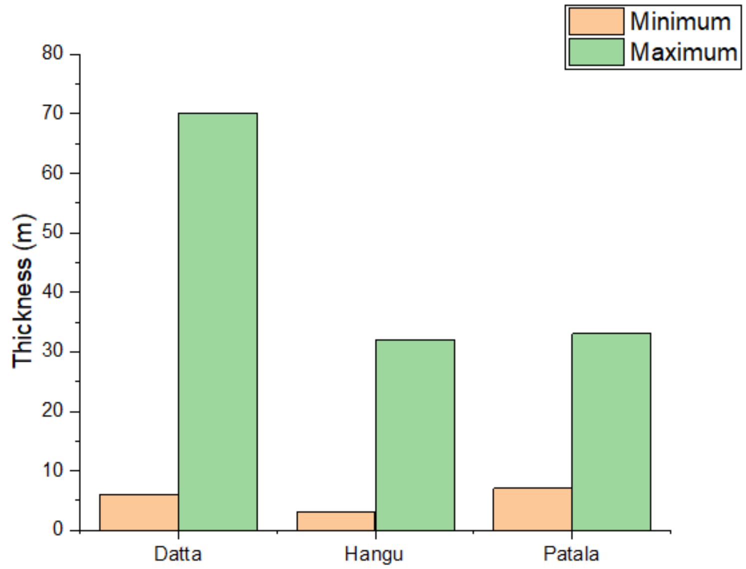
## Thickness of shale gas formations In North Korea:-

| Shale Play | Minimum Thickness (m) | Maximum Thickness (m) |
|---|---|---|
| Barnett | 30 | 185 |
| Haynesville | 60 | 90 |
| Antrim | 21 | 70 |
| New Albany | 15 | 30 |
| Eagle Ford | 30 | 145 |
| Fayetteville | 6 | 60 |
| Montney | 45 | 305 |
| Duvernay | 20 | 70 |



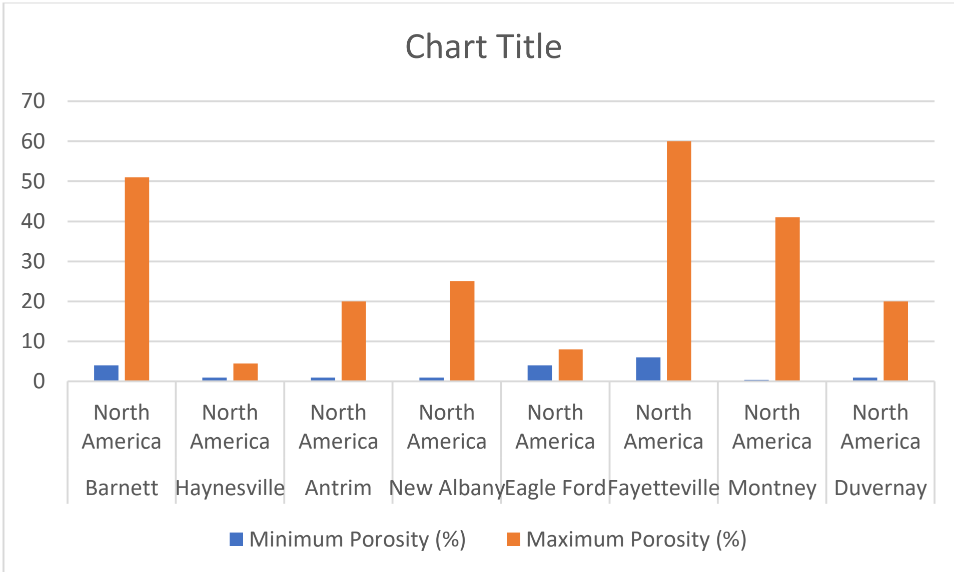

## Thickness of shale gas formations In Pakistan:-

| Formation | Minimum Thickness (m) | Maximum Thickness (m) |
|---|---|---|
| Datta | 6 | 70 |
| Hangu | 3 | 32 |
| Patala | 7 | 33 |

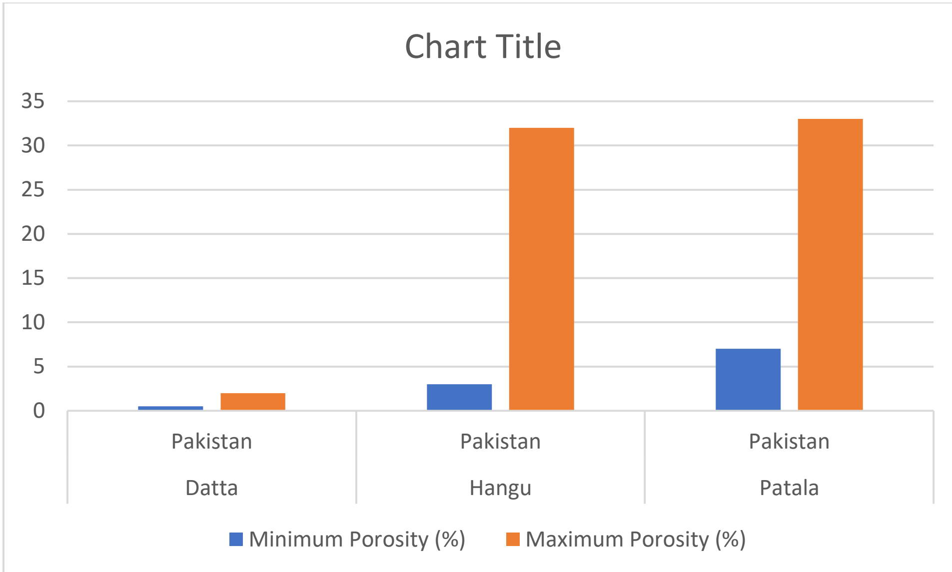



## Porosity Comparison of North American and Pakistani Shale Formations :-

| Formation | Region | Minimum Porosity (%) | Maximum Porosity (%) |
|---|---|---|---|
| **Barnett** | North America | 4 | 51 |
| **Haynesville** | North America | 1 | 4.5 |
| **Antrim** | North America | 1 | 20 |
| **New Albany** | North America | 1 | 25 |
| **Eagle Ford** | North America | 4 | 8 |
| **Fayetteville** | North America | 6 | 60 |
| **Montney** | North America | 0.4 | 41 |
| **Duvernay** | North America | 1 | 20 |




| Formation | Region | Minimum Porosity (%) | Maximum Porosity (%) |
|---|---|---|---|
| **Datta** | Pakistan | 0.5 | 2 |
| **Hangu** | Pakistan | 3 | 32 |
| **Patala** | Pakistan | 7 | 33 |




## Discussion

The combination of both hydroponics and extraction of shale gas in the country provides a response to the complex issues of food security and energy problems in Pakistan. Based on the findings of both projects, this discussion considers the implications for the future of Pakistan's agriculture and energy.

### Hydroponic Farming: Addressing Food Security

Hydroponic farming can thus be seen as an adequate substitute for the conventional form of farming system in areas with scarce water resources and deteriorating soil compatibility. The findings of this research suggest that hydroponically grown crops including spinach, performed better in growth indices than traditionally grown crops. This relates to the current studies that show that hydroponics is effective in producing high yields for crops with fewer resources used (*Oztekin*, n.d.)(Ravindra B. Malabadi et al., 2024). Considering the prevailing conditions of Pakistan, the benefits of the ability to control nutrient delivery precisely are related to the optimization of the conditions that promote plant growth, which are otherwise difficult to achieve due to unfavorable weather conditions in the country.

Another major benefit of hydroponic systems is water conservation Water is an essential resource in the production of food crops and other related produce. Thus, research revealed that hydroponics utilizes as little as 30% of the water compared to the traditional farming system. This is especially important since Pakistan continues to face acute water shortage issues owing to climate change and the under-represented water resources(Ingrao et al., 2023; Khudoyberdiev et al., 2020) . The hydroponics technology offers Pakistan an opportunity to reduce water usage in agriculture significantly but increase the productivity of fertilizers.

Hydroponics entails the establishment of many systems, but the result is the use of less water and fertilizer hence more economical in the long run. An earlier study estimated that the total cost for establishing a hydroponic unit was PKR 9680, although this investment results in cost savings in the long-run because of reduced operational costs(Baloch et al., 2017) . Also, the increased prospect of reaping higher yields could boost farmers 'revenues hence the idea of hydroponics would benefit the small holder farmers who are often affected by food insecurity.

Hydroponics, in addition, can also be used in urban agricultural systems because space may be a limiting factor in most urban areas. This approach not only addresses the issue of food insecurity but also additionally decreases emissions related to movement of edibles(Pavlovic et al., 2021) **.** As cities are rapidly growing, incorporating hydroponics into city planning might be a way forward in addressing food deficit planning.

The study also provides evidence on the need to adopt government support policies to facilitate acceptance and implementation of hydroponic farming in Pakistan. Hybrid marketing opportunity such as CPEC now offers new opportunities in marketing value added crops in hydroponics. By offering funds to farmers and teaching them about technically correct farming methods, the government helps shift to environmentally friendly farming(Fleck et al., 2012) .

**Shale Gas Development: A Pathway to Energy Security**

This has made it even more alarming to admit that Pakistan has been facing severe energy crisis due to increasing demand of natural gas. From the consequences derived from this study, it is most apparent that the development of shale gas resources may go a long way in mitigating this crisis. Although abounding with estimated reserves of 105 trillion cubic feet of shale gas(*EIA 2013*, n.d.) , Pakistan has abundant scope to exploit this valuable resource through technologies like hydraulic fracturing.

The geological appraisal further identified formations such as Datta, Hangu, Patala, Ranikot, Sembar, and Lower Goru as potential shale gas play because of their characteristics (*Mohyuddin*, n.d.). However, successful implementation of extraction will call for consideration of environmental issues related to hydraulic fracturing. As a result, regulatory conditions have proven to be essential in minimizing risks connected to the pollution of ground waters and potential future seismic activity, as (Esterhuyse et al., 2014) have pointed out.

Cost factors that will warrant development of more shale gas projects will include technological development in drilling techniques as well as efficient management of reservoirs(*Guo C*, n.d.-b) . There is a possibility of improving energy security and at the same time adopting renewable energy policies when shale gas development is combined with the promotion of renewable energy. The depleting oil and gas resources of Pakistan have forced the country to look forward to some extent of energy diversification, particularly the exploration of indigenous resources such as shale gas can decrease the dependency on imported fuels for power generation.

Besides, the future global demand for natural gas is on the rise and Pakistan has large prospects of shale gas and could therefore play a key role in the global market. This potential supports what, according to(*Husain A*, n.d.) **,** is the need to cultivate domestic power resources to power the domestic market as simultaneously searching for export markets.

## Synergistic Potential: Sustainability Analysis of Introducing Hydroponics to Shale Gas Development

Hydroponic farming integrated with shale gas can help Pakistan in a way to overcome two main issues: food scarcity and energy crisis. Technological advancement in the extraction of shale gas makes them a perfect source of clean energy which could be used to run hydroponic system in performing their functions effectively(Bundschuh & Chen, 2014). This synergy not only improves the productivity of agriculture but also assists in sustainable development since it creates employment opportunities in both sectors.

Perhaps, the economic returns generated from shale gas production could be used to improve agricultural technologies like hydroponics. This reinvestment could possibly deliver better fruits and vegetable production infrastructure whilst serving the energy needs at the same time(*AFDC 2014*, n.d.) **.** When the energy sector collaborates with the agriculture sector it becomes easy for the country to withstand shocks that result from fluctuations in the international market.

Additionally, the global demand for natural gas is expected to increase in the future, and Pakistan's shale gas reserves may well place Pakistan on the world map of energy producers. Regarding this potential (Mallick, 2014) also supports it by stating that it is necessary to foster indigenous resources for domestic consumption coupled with a search for export market.

## Challenges and Considerations

Several impacts have to be considered in order to overcome challenges of food security and energy sustainability during both projects. Looking at hydroponics, one of the main challenges they have is the high capital requirements which will be costly to smallholder farmers who cannot access credit facilities. Further, there is a recognized demand for technical education and training, and support services regarding the management of hydroponic systems by farmers(Nguyen et al., 2022) .

Also, educational tools that would be disseminated to the populace are paramount in seeking to have acceptance within the populace. Awareness creation on the use and advantages of soil less farming method may go a long way to eliminating myths about crop production through such methods compared to conventional farming methods(Govaerts* et al., 2009).

That is why concerns about environmental impact continue to be a key consideration with regard to shale gas development. Separate studies have linked hydraulic fracturing to risks of groundwater pollution and seismicity in different parts of the globe(Esterhuyse et al., 2014)**.** Consequently, it is high time policymakers set standards for formulating extraction policies on the one hand while promoting fairness of operations on the other end.

Also, local community opposition or NIMBYism may be expected because of various environmental risks related to the operation of shale gas extraction. There are few better ways of building trust for these initiatives than by including the local communities in the decision making processes and addressing their concerns(Cavaye, 2001).

Therefore, hydroponic farming and shale gas development can easily be categorized as perfect responses to the current issues that Pakistan faces in terms of food insecurity, as well as energy security. By embracing the modern technologies and environment friendly practices in both sectors Pakistan has the ability to make a better future for its increased population and resources.

As is shown by the findings presented in this research, there are very good reasons to consider investing in these two areas at the same time. Policy makers have to promote friendly legal requirements towards facilitating investment for hydroponics and shale gas as well as guarantee the existence of protective measures for the environment(Singh et al., 2023). Balancing and integrating the agriculture and energy sectors are relevant aspects in Pakistan and therefore, through effective and careful planning of the Country leaders with the support of scientists, policymakers, farmers, and other industry leaders, Pakistan can definitely play a role in sustainable growth should be tapped. This discussion builds upon concepts regarding both projects but ensures that concepts derived from the given list of references are integrated in this discussion as required.

## Author Contributions:

A.U.R devised the idea for this research. A.U.R is the main author of the methodology, validation, formal analysis, investigation, data curation, writing of the original draft and review of subsequent versions. T.J revised this manuscript.

**Funding:** this study received no external funding.

**Data Availability**: The datasets _generated and/or analyzed during the current study are not publicly available due to privacy reasons but are available from the corresponding author on reasonable request.

**Declarations:**

Ethics Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

**Competing Interests:**

The authors declare no competing interests.

**References :-**

*AFDC 2014*. (n.d.).

Baloch, M. H., Abro, S. A., Kaloi, G. S., Mirjat, N. H., Tahir, S., Nadeem, M. H., Gul, M., Memon, Z. A., & Kumar, M. (2017). A research on electricity generation from wind corridors of Pakistan (two provinces): A technical proposal for remote zones. *Sustainability (Switzerland)*, *9*(9). https://doi.org/10.3390/su9091611

*Boyer C*. (n.d.).

*Bradely*. (n.d.).

Bundschuh, J., & Chen, G. (2014). *Sustainable energy solutions in agriculture*. CRC Press.

Cavaye, J. (2001). Rural community development-New challenges and enduring dilemmas. *Journal of Regional Analysis and Policy*, *31*(2).

*Cipolla Cl*. (n.d.).

*EIA 2011*. (n.d.).

*EIA 2013*. (n.d.).

*EIA 2016*. (n.d.).

Energy Information Administrtion, U. (2014). *AEO2014 Early Release Overview*. http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=microdata.

Esterhuyse, S., Avenant, M., Redelinghuys, N., Kijko, A., Glazewski, J., Pitt, L. A., Kemp, M., Smit, A., Sokolic, F., & Vos, A. T. (2014). *Development of an interactive vulnerability map and monitoring framework to assess the potential environmental impact of unconventional oil and gas extraction by means of hydraulic fracturing*.

Fleck, S., Raspe, S., & Čater, M. (2012). *Leaf area measurements*. https://www.researchgate.net/publication/256442353

Govaerts∗, B., Verhulst∗, N., Castellanos-Navarrete, A., Sayre, K. D., Dixon, J., & Dendooven, L. (2009). Conservation agriculture and soil carbon sequestration: between myth and farmer reality. *Critical Reviews in Plant Science*, *28*(3), 97–122.

*Guo C*. (n.d.-a).

*Guo C*. (n.d.-b).

*Husain A*. (n.d.).

Ingrao, C., Strippoli, R., Lagioia, G., & Huisingh, D. (2023). Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks. *Heliyon*, *9*(8), e18507. https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e18507

*Key results from AEO2015 2*. (n.d.).

Khudoyberdiev, A., Ahmad, S., Ullah, I., & Kim, D. H. (2020). An optimization scheme based on fuzzy logic control for efficient energy consumption in hydroponics environment. *Energies*, *13*(2). https://doi.org/10.3390/en13020289

Mallick, S. K. (2014). Disentangling the poverty effects of sectoral output, prices, and policies in i ndia. *Review of Income and Wealth*, *60*(4), 773–801.

*Mohyuddin*. (n.d.).

Nguyen, T. P. D., Vu, N. T., Tran, T. T. H., Nguyen, Q. T., Cao, P. B., Kim, I. S., & Jang, D. C. (2022). Growth and Quality of Hydroponic Cultivated Spinach (Spinacia oleracea L.) Affected by the Light Intensity of Red and Blue LEDs. *Sains Malaysiana*, *51*(2), 473–483. https://doi.org/10.17576/jsm-2022-5102-12

*Oztekin*. (n.d.).

Pavlovic, J., Kostic, L., Bosnic, P., Kirkby, E. A., & Nikolic, M. (2021). Interactions of Silicon With Essential and Beneficial Elements in Plants. In *Frontiers in Plant Science* (Vol. 12). Frontiers Media S.A. https://doi.org/10.3389/fpls.2021.697592

Ravindra B. Malabadi, Kiran P. Kolkar, Raju K. Chalannavar, Karen Viviana Castaño Coronado, Simuzar S. Mammadova, Himansu Baijnath, Antonia Neidilê Ribeiro Munhoz, & Gholamreza Abdi. (2024). Greenhouse farming: Hydroponic vertical farming- Internet of Things (IOT) Technologies: An updated review. *World Journal of Advanced Research and Reviews*, *23*(2), 2634–2686. https://doi.org/10.30574/wjarr.2024.23.2.2595

*Role of Hydroponics in Improving Water-Use Efficiency and Food Security*. (n.d.).

Singh, B. J., Chakraborty, A., & Sehgal, R. (2023). A systematic review of industrial wastewater management: Evaluating challenges and enablers. *Journal of Environmental Management*, *348*, 119230.

Wainberg, M., Foss, M. M., Gülen, G., & Quijano, D. (2017). Current and future natural gas demand in China and India. *Center for Energy Economics, The University of Texas at Austin: Austin, TX, USA*.