[***ENERGIES***](https://www.mdpi.com/journal/energies)



Review

**Energy Consumption Reduction and Sustainable Development for Oil & Gas Transport and Storage Engineering**

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**Citation:** Chen, X.; Wang, M.; Wang, B.; Hao, H.; Shi, H.; Wu, Z.; Chen, J.; Gai, L.; Tao, H.; Zhu, B.; et al. Energy Consumption Reduction and Sustainable Development for



Oil & Gas Transport and Storage Engineering. Energies **2023**, 16, 1775. <https://doi.org/10.3390/en16041775>

Academic Editor: Albert Ratner

Received: 21 December 2022

Revised: 5 January 2023

Accepted: 17 January 2023

Published: 10 February 2023



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**Abstract:** The oil & gas transport and storage (OGTS) engineering, from the upstream of gathering and processing in the oil & gas fields, to the midstream long-distance pipelines, and the downstream tanks and LNG terminals, while using supply chains to connect each part, is exploring its way to reduce energy consumption and carbon footprints. This work provides an overview of current methods and technological improvements and the latest trends in OGTS to show how this industry strives to achieve sustainable development goals. The critical analyses are from increasing flexibility, energy saving, emission reduction, and changing energy structure. The study shows the need to focus on improving energy efficiency further, reducing energy/water/material consumption and emissions, and maintaining safety for such an extensive oil & gas network.

**Keywords:** oil & gas; transportation; storage; sustainability; energy reduction

**1. Introduction**

With the proposal of “dual carbon goals”, many industries stepped up the pace to introduce a series of green and low-carbon transformation and development measures. This also happens to the energy-intensive oil industry, especially regarding reducing energy consumption and improving resource utilisation rates. For the specific oil and gas transport and storage (OGTS) sector, many process-wide, site-side, and system-wide measures are taken to analyse the carbon emission situation of pipelines and storage tanks, to explore the energy saving potential, and to achieve the target of energy consumption reduction.

It is crucial to analyse how current technologies contribute to sustainable OGTS engi-neering. A recent review by Liao et al. [1] studied the effective and low-carbon operation of petroleum pipelines, especially for monitoring, control, and operation. They found that to achieve a “smart pipeline network”, there are still lots of tasks that should be done. With the development of big data, cloud computing, and blockchain, energy consumption and carbon emissions for petroleum pipelines can be further reduced. Although their review primarily focused on petroleum pipelines, some supply chain papers were also discussed.

Another interesting study done by Huang et al. [2] conducted a comprehensive life cycle assessment of analysing carbon emissions of an oil products pipeline system from construction to disposal (carbon footprint of oil products pipeline transportation). They concluded that the connection of the oil pipeline network and the all-around supply of oil products could contribute to a great emission reduction.

However, these two papers only discussed developments for pipelines or specifically oil product pipelines, but without focusing on the sustainable development for OGTS

Energies **2023**, 16, 1775. <https://doi.org/10.3390/en16041775> <https://www.mdpi.com/journal/energies>

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gineering, which covers a wider perspective, e.g., upstream oil & gas field, LNG, and su ply chain issues.

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withsupplyabroaderchain issuesperspective. and discusses possible directions for further research. Th

Compared to previous reviews, this work provides a more comprehensive analysis structure and tasks for OGTS engineering are shown in Figure 1. This paper is based o

with a broader perspective and discusses possible directions for further research. The

this structure, to summarise the development of sustainable oil and gas transportatio structure and tasks for OGTS engineering are shown in Figure 1. This paper is based on

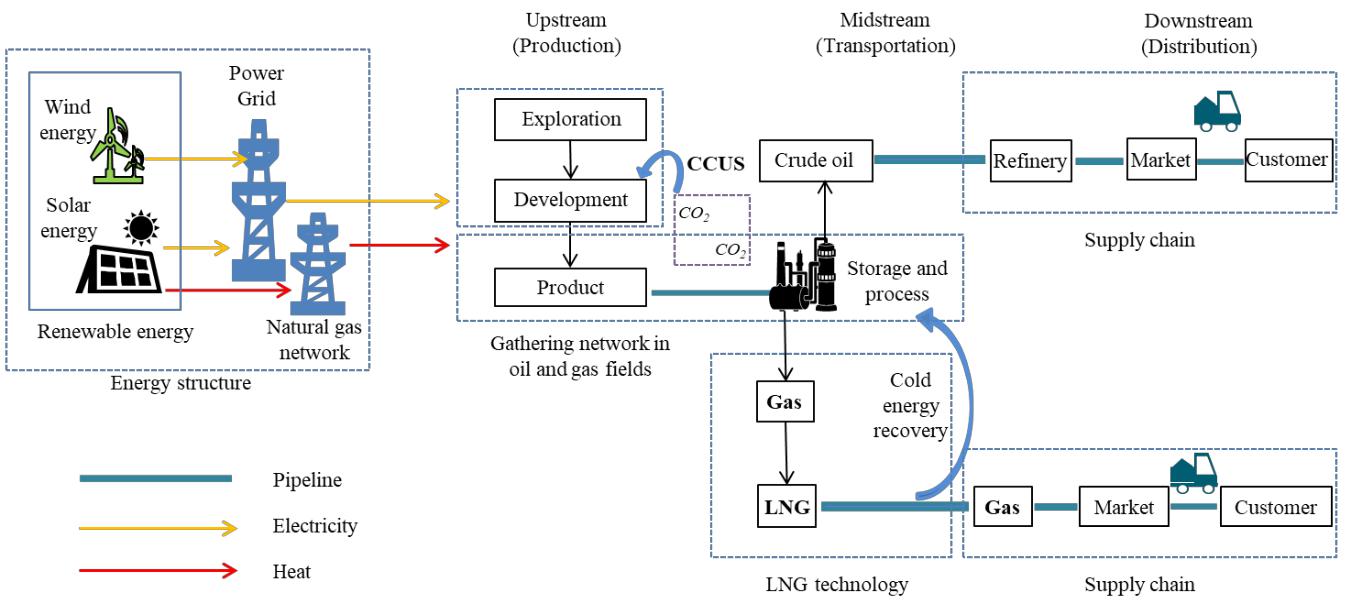
and storage from the perspectives of gathering and processing in oilfields, long-distan this structure, to summarise the development of sustainable oil and gas transportation

pipelines,andstoragesupplyfromchains,theperspectivesLNGtechnologiesofgatheringand processingOGTS-relatedinoilfields,energylongstructure-disance change

Suggestionspipeline, aresupproposedlychains, LNGforenterprisestechnologiestoandbetterOGTSdesign-relatedtheenergycorrespondingstructurechangessystems. an

Suggestions are proposed for enterprises to better design the corresponding systems and achieve sustainable development.

achieve sustainable development.



**FigureFigure1.**Structure**1.**andandtasks for oil&&gasgastransportandandstoragestorageengineeringengineering..

* 1. **Sustainable OGTS Development in Oilfields**

1. **Sustainable OGTS Development in Oilfields**

For the OGTS sector in the oilfield, the main tasks are gathering oil from wells through gatheringForthe stationsOGTS tosectorcentralinprocesstheoilfield,facilities,thethe mainoilandtasksgastreatment,aregatheringandstoringoil thefrom wel

throughcrudegatheringoiltanksstationsbeforetotransportingcentralprocessthecrudefacilities,oilusingthepipelinesoiland.A gassketchtreatment,diagramisand sto

ing theshowncrudeinFigureoilin2.theThetanksleftsidebeforeisthe gatheringtransportingsystem,thewhichcrudeincludesoilusingwells,pipelinesgathering.A sketc stations, and pipelines for connection. Pumps or compressors are needed in this system

diagram is shown in Figure 2. The left side is the gathering system, which includes well as the oil and gas gathered from wells may need to be pressurised and transported to the

gathering stations, and pipelines for connection. Pumps or compressors are needed in th processing system. And heat is required for some cases as the oil needs to be warmed to

system as the oil and gas gathered from wells may need to be pressurised and transporte increase its mobility. For processing system, oil and gas should be processed to make

to thecommercialprocessingproductsy**s**.temThe. energyAnd heatconsumptionisrequiredinoilfieldsfor issomerelativelycaseshigh,as exctheptoilforneedsthe to b

warmeddrilling,to energyincreaseisrequireditsmobilityforcrude.Foroil transport,theprocessingacidgas systemtreatment,oilandandgas dehydrationgasshould. be pr

However, with the low level of energy management strategy in some of the oilfields, the cessed to make commercial products. The energy consumption in oilfields is relative

energy utilisation efficiency has great potential to be improved.

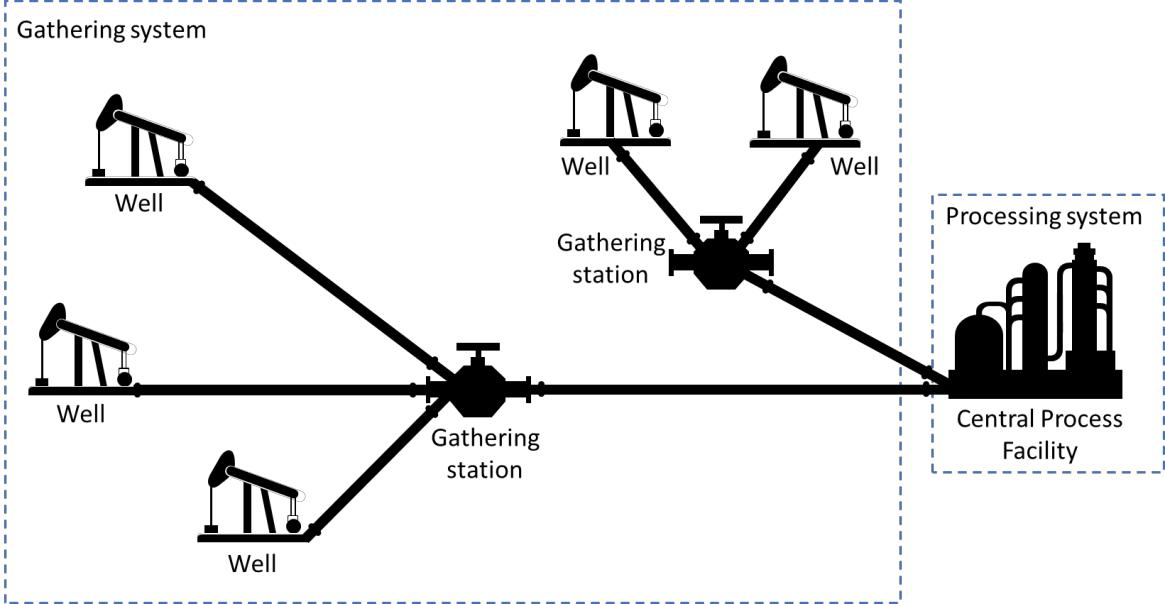
high, except for the drilling, energy is required for crude oil transport, acid gas treatmen Some studies focused on oilfield development in specific conditions, such as low

and gas dehydration. However, with the low level of energy management strategy oil prices. For example, song et al. [3] studied and expounded on the difficulties faced

somebyofChina’stheoilfields,oilfield developmenttheenergyutilisationunderthe oilefficpr**i**encyce,analyhasedgreatthe potereaso**n**tialsfortotheberiseimproved

of development costs, put forward the methods of low-cost oilfield development, and predicted the development potential and prospects of China’s oilfields.

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**Figure 2.** A sketch diagram of gathering and processing systems in oil & gas fields.

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2.1Some.GatheringstudiesSystemfocused on oilfield development in specific conditions, such as low oil

prices. For example, song et al. [3] studied and expounded on the difficulties faced by For the gathering processes, many papers focus on reducing the pump and compressor

Chinacosts’s tooilfieldsaveenergydevelop.Pu**m**entpsandundercompressorstheoilprice,aretheanalysmain**e**dquipmentthereasonsused forinthetheoilfieldriseof de-velopmentforoilandcosts,gaspressurisation,putforward andthe theymethodsoccupyofhigherlow-costpercentagesoilfield indevth**e**lopment,transport costand. pre-

dictedThe targetsthedevelopmentforsomeworkspotentialaretransportandprospectscostreductionofChinaortotal’soilfieldscostreduction,. and these aims both contribute to the energy reduction of this pressurisation equipment.

Wang et al. [4] optimised oilfield transportation water systems based on environmental *2.1. Gathering System*

and economic benefits. The location of central process facilities, pipeline and truck transport

For the gathering processes, many papers focus on reducing the pump and compres-

modes, and hydraulic requirements for pipelines are considered. An oil field in China

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costthe.Thecosttargetsofthecurrentforsomesystemworks.Zhouare ettr**a**lnsport.[5]consideredcostreductiontheenergyortotalconsumptioncostreduction,costof and

compressors as part of the objective function in a coalbed methane field design optimisation these aims both contribute to the energy reduction of this pressurisation equipment. model, together with the nodes, flow rate, and gathering mode constraints, to determine

Wang et al. [4] optimised oilfield transportation water systems based on environmen-

the profit-maximisation design scheme. As the power of compressors is optimised, the

tal and economic benefits. The location of central process facilities, pipeline and truck model helps to reduce energy consumption. These above references integrated the energy

transport modes, and hydraulic requirements for pipelines are considered. An oil field in consumption of pumps and compressors when performing a design task of oil and gas

China was studied as an example, and the results showed that a better pipeline diameter fields. In this way, a balance between the profit and operating cost can be achieved, and

could contribute to CO emission and total cost reduction by 65.07% and 25.28% compared energy consumption can2 be reduced.

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case was studiedtogetherdetermine the location and sizing of tank batteries for oil and gas

sation model, with the nodes, flow rate, and gathering mode constraints, to de-separation, and pipeline connections. Almedallah et al. [7] developed an integrated ap-termine the profit-maximisation design scheme. As the power of compressors is opti-

proach for wellbore trajectory.Pipeline network routes and platform locations were planned mised, the model helps to reduce energy consumption. These above references integrated

based on Constrained Optimisation by Linear Approximation and Mixed Integer Linear

the energy consumption of pumps and compressors when performing a design task of oil

Programming. The method was successfully used in an offshore oilfield in the Gulf of

and gas fields. In this way, a balance between the profit and operating cost can be Mexico for planning. Zheng et al. [8] proposed a method to increase production by in-

achieved, and energy consumption can be reduced.

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caseof wasfacilitiesstudiedand electricitytodetermine.The mainthelocationvariablesandare thesizingpositionsoftanktoinstallbatteriesthecompressor,foroiland gas flow rates of pipelines, and pressures of nodes. A two-stage improved genetic algorithm

separation, and pipeline connections. Almedallah et al. [7] developed an integrated ap-proach for wellbore trajectory.Pipeline network routes and platform locations were planned based on Constrained Optimisation by Linear Approximation and Mixed Integer Linear Programming. The method was successfully used in an offshore oilfield in the Gulf of Mexico for planning. Zheng et al. [8] proposed a method to increase production by

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and particle swarm optimisation (PSO) algorithm was proposed to solve this problem. The case results showed that the power consumption of the compressor could be reduced as much as possible on the premise of increasing the output. Zhao et al. [9] studied an oil field and deduced the temperature drop and pressure drop model of oil, gas and water three-phase flow. Taking four wells in a block of Tahe oilfield as an example, the operation parameters of single well gathering and transportation, branch connection gathering and transportation and annular gathering and transportation were determined. The energy consumption and operation cost were calculated. The comparative analysis results showed that the most energy-saving gathering and transmission mode of these four wells is the branch connection mode of pipe network.

With the continuous development of the oilfield, the increase of water cut and the number of shut-down wells, the existing gathering and transportation production mode of the oilfield can no longer meet the requirements of energy conservation. Measures should be taken for reconstruction. Wang et al. [10] studied the transformation of the pipeline system in the middle and late stages of oilfield development, taking into account the hydraulic power, technology and transformation cost. The mixed integer nonlinear programming model was established and solved by a branch and bound algorithm. The results showed that the total cost is reduced by 7.13% after the pipeline restructured according to the proposed method. Bai et al. [11] aimed to reduce the energy consumption of high water-cut oilfields. The node analysis method was applied to integrate the injection, reservoir, and production system, and a model was developed to calculate the energy consumption of the integrated system. The adjusted liquid production rate, injection-production ratio, splitting coefficient, and target formation pressure level were set as variables. The PSO algorithm was used with the reservoir numerical simulation to optimise the production plan. The integration system can save 8% of energy consumption.

Offshore floating production, storage and operation (FPSO) is a key facility for offshore oil development, mainly used for the exploitation, processing, storage and outward transporta-tion of offshore oil, natural gas and other energy sources. Allahyarzadeh-Bidgoli et al. [12] considered the operation modes of various FPSO, including maximum oil/gas content, 50% basic sediment and water, and maximum water/CO2 content, analysed the output pressure and fluid temperature of each component of the system, and obtained the parame-ters related to energy consumption and total oil production.

2.2. Oil and Gas Process System

In terms of oil and gas processing, there are also many studies to achieve energy conservation and consumption reduction. This kind of research focuses on improving the recovery rate of energy, especially the recovery efficiency of heat energy. By adjusting the arrangement of heat exchangers, the heat of the hot stream can be transferred to the cold stream as much as possible to avoid the waste of energy.

Zhang et al. [13] proposed a two-stage method to optimise the energy consumption of natural gas field purification plants. Both operating variables and the heat exchanger network were optimised. The results showed that 41.5% of energy consumption could be reduced compared to the current site after optimisation.

2.3. Pollution Reduction

Recently, the progress of oilfield-produced water treatment technologies aroused much research attention and they were reviewed by several studies. Pollution reduction should be considered in both design and operating periods. For the design period, the target is to reduce the potential emission or pollution and also keep a balance between the construction cost. For some projects, there is a trade-off between the construction cost and environmental cost. For example, the site could leave far away from the residential area to reduce the impact on humans, but correspondingly increase the pipeline construction and transportation costs. Some researchers considered the trade-off in the design period and developed some methods. Wang et al. [14] studied the site selection of gas gathering

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stations, considered economic and environmental factors, established a model with the objective function of minimum construction cost and environmental impact, used the coupled A-star algorithm to find the optimal path, and used the Monte Carlo method to sample the uncertain wind data to assess the environmental effect. The results showed that this method can solve the optimal site of the gas gathering station.

Li et al. [15] studied the energy consumption prediction of oil and gas companies to improve the energy efficiency of oil and gas production. Four methods were tested, in-cluding support vector machine, linear regression, extreme learning machine, and artificial neural network. The results showed that the hybrid model of the extreme learning machine and the artificial neural network has the best performance.

Amakiri et al. [16] introduced the characteristics of the oilfield and used a variety of technologies to evaluate the different stages of produced water. They discussed the effectiveness of the treatment technology from the aspects of pollutant treatment effect, and made a qualitative evaluation from the aspects of energy demand, robustness and flexibility, power generation, modularity and mobility. Ghafoori et al. [17] summarised the optimal management strategy, source and characteristics of oilfield sewage, discharge regulations, treatment management, and physical, chemical, thermal, biological, membrane, and mixed treatment technologies. The challenges and future directions for oilfield-produced water treatment were discussed. Samuel [18] concentrated on conventional and membrane-based technologies for oilfield-produced water treatment. The method reviewed in the paper includes physical and chemical treatment processes, biological treatment processes and physical treatment processes. That paper expounded on the technical advantages and technical bottlenecks as well as alleviated the technical bottlenecks. Liu et al. [19] studied the treatment of produced water from offshore oil fields. They proposed a full-scale process treatment technology considering that the traditional technology could not meet the requirements of separating organic pollutants in a compact space under extreme conditions. The results showed that about 100 kinds of organic compounds in oilfield-produced water treated by this process are reduced to 8 types, and the separation efficiency is more than 90%. Wu et al. [20] focused on the oilfield-produced water and sulfide production in the petroleum industry, considering the factors of reducing produced water and sulfide in oil production and improving the utilisation rate of iron. They developed a chemical method of iron-crosslinked sodium alginate. The results showed that with this method, the sulfide in the gas phase is reduced by 45 3.2%, the sulfide in the aqueous solution is reduced by 75 4.7%, and the crude oil standardised produced water decreases from 70.1 4.0 to 37.5 1.3 mL water/mL oil.

The effect of oil as an extractant to reduce the oil content in oilfield-produced water was studied and evaluated by de Carvalho Neto et al. [21], taking into account physical and chemical parameters such as pH value, temperature, mixing speed and time, oil type and concentration, initial concentration of naphthenic acid, etc. They first used oil as an extractant to conduct experiments in synthetic oilfield-produced water, and then evaluated the process of removing oil and grease content in actual oilfield-produced water. The results showed that the removal efficiency of oil and grease is about 60% when the pH value of the produced water of synthetic petroleum is in the range of 2–5.

Esmaeilnezhad and Choi et al. [22] studied electrorheological suspension to form a solid-like structure in porous media to block the pore throat and reduce the amount of oilfield-produced water. They proved the feasibility of the proposed method through experiments.

Cao et al. [23] studied the treatment of high-salt oilfield wastewater (HSOW), consid-ering the complex composition and low biodegradability of HSOW. The HSOW treatment system combining air flotation and biochemical technology with constructed wetlands (CW) was studied. At high salinity (1.36~2.21 104 mg/L), the integrated treatment system can effectively remove COD, NH4+-N and oil, and the average removal rates are 98.5%, 99.9% and 96%.

Chen et al. [24] studied the characteristics and environmental impact of oxygenated volatile organic compounds (OVOCs) related to oil and gas in China. Taking an oil field

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and a rural area in the Yellow River Delta region in the winter and summer of 2017 as an example, the C1–C8 carbonyl group, which is an important member of the OVOCs family, was measured. Spatially, due to the strong emission of hydrocarbon precursors from the oil field, the measured concentration of carbonyl compounds in the oil field is higher than that in rural air. Their study quantitatively revealed the effect of oil field emissions on the photochemical formation of major carbonyl compounds.

2.4. Carbon Dioxide Capture, Utilisation and Storage (CCUS)

Carbon dioxide will be produced in the process of oil field exploitation. To reduce CO2 emission in oil field development, some studies focused on the technology of carbon dioxide capture, utilisation and storage (CCUS), and the feasibility and economy of this technology were evaluated. Besides, evaluation models to assess the CCUS systems were established.

Xin et al. [25] studied the compression and liquefaction of CO2 and proposed a scheme to use the cold energy of liquid natural gas to compress and liquefy CO2. The results showed that the scheme is feasible and can effectively reduce the total cost of compressed liquefied CO2. Leonzio et al. [26] discussed the CCUS system and supply chain in the UK. They developed a mathematical model for the CCUS supply chain, the connections between the CO2 source and sinks, and the amount of captured CO2 was optimised. The case results found that for the UK, the most effective solution is to use the Scottish offshore and Ormskirk Sanders as storage sites. This solution can minimise the total cost of the CCUS system and supply chain. El-kaseeh et al. [27] discussed using three geophysical methods to obtain three-dimensional seismic data, and combined these three data with downhole measurement data to improve oil recovery and CO2 storage and monitoring effi-ciency. Andersen et al. [28] introduced the latest technologies for stabilizing CO2 foam with nanoparticles, on-site tracking of CO2, characterisation of potential CO2 storage sites, CO2 injection technology and gas adsorption. This article provides useful information for CO2 joint storage or utilisation in particularly dense shale and carbonate rocks. Suicmez [29] eval-uated the feasibility of implementing carbon capture, storage and utilisation projects in the North Sea Cretaceous oil field, and estimated the development costs of such projects. The research results showed that about 100 M barrels of additional oil reserves can be released by injecting CO2, and 40 Mt of CO2 are trapped in the reservoir. Fukai et al. [30] proposed a cost-benefit analysis method to evaluate the economic feasibility of CO2-enhanced oil recovery in Ohio. Break even correlation is used as an independent index for project screen-ing to determine that CO2 is a feasible purchase to enhance oil recovery. Li et al. [31] studied CO2 enhanced oil recovery and storage technology, a multi-parameter dimensionless quick screening model was integrated with the reservoir compositional simulation to evaluate the CO2 enhanced oil recovery and storage potential, which is a major from of CCUS and is an economic and effective way to reduce CO2. The case of HZ2-1 oilfield in the Pearl River Mouth Basin in the northern South China Sea, Guangdong Province was studied and tested the proposed method. Lv et al. [32] focused on the geological characteristics of the reservoir in the demonstration area of Shengli Oilfield, proposed an optimisation evaluation method for CO2 oil displacement and storage, designed a multi-stage umbrella downhole gas separator, and successfully developed a high gas oil ratio production string and a free kill gas injection string for CO2 enhanced oil recovery and storage. Yang et al. [33] evaluated cyclic projects that connect capture and injection inside the oilfield. For the Recycle-CO2 capture and storage (CCS)-Enhanced Oil Recovery (EOR) (RCE) project, considering the uncertainty of geological conditions, price and CO2 injection volume, a comprehensive technical and economic model was proposed to analyse economic and environmental bene-fits. The breakeven oil price with and without carbon water, the recommended injection amount of CO2, and the reasonable investment amount were compared. Compared with three times of traditional oil recovery, the carbon emission of RCE project has been reduced by about 54.7%.

Currently, the studies on CCUS in China have increased, including the public’s aware-ness of environmental protection, the impact of different government subsidy schemes

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schemes on the investment benefits of CCUS projects, and the current situation of CCUS projects in China.

Jiang et al. [34] studied the number of relevant articles on CCUS in China and found on the investment benefits of CCUS projects, and the current situation of CCUS projects

that the number of publications on research in this field has increased. In addition, the in China.

author found that the current research frontiers include “pipeline”, “shale gas” and Jiang et al. [34] studied the number of relevant articles on CCUS in China and found “steel”, and put forward suggestions to improve research in these fields from the perspec-

that the number of publications on research in this field has increased. In addition, the tiveauthofr foundgovernmentthattheinterventioncurrentresearch.Lietfrontiersal.[35]includeconducted“pipeline”,anationwide“shalegas”surveyandon“steel”,thepub-licand’s understandingputforwardsuggestionsoftheenvironmentaltoimprove reseimpactrchandin thesetechnicalfieldsfrommanagementheperspectiveofthe en-vironmeofgover**n**menttalprotectionintervetiontechnology.Lietalcentre.[35].conductedThesurveya nationwideresultscan bettersurveyhelpon therelevantpub- en-vironmentallic’sunderstandingdepartmentsofthe environmentalpromotethedevelopmentimpactandtheandtechnicaldeploymentaagementofenvironmentalfthe protectionenvironmentaltechnologyprotection.Li tetchnologyal.[36]describedcentre.Thethesurveycurrentresultssituationcanbetterandanahelplysedrlevantthepro-

environmental departments promote the development and deployment of environmen-spects of CCUS in China, and put forward some appropriate suggestions. Yang et al. [37]

tal protection technology. Li et al. [36] described the current situation and analysed the established an evaluation model to evaluate the characteristics of Dagang Oilfield, ana-prospects of CCUS in China, and put forward some appropriate suggestions. Yang et al. [37] lysed the crude oil properties of the oilfield, and conducted CO2 enhanced oil production

established an evaluation model to evaluate the characteristics of Dagang Oilfield, analysed test and risk assessment for a sub-oilfield of Dagang Oilfield. The research results provide the crude oil properties of the oilfield, and conducted CO2 enhanced oil production test

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At present, CO2 is mainly used or stored in refineries, for enhanced oil recovery, to

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displace coalbed methane, or stored in depleted oil and gas reservoirs. Although CCUS is At present, CO2 is mainly used or stored in refineries, for enhanced oil recovery, developed very fast, there are still several challenges that should be stressed (Figure 3).

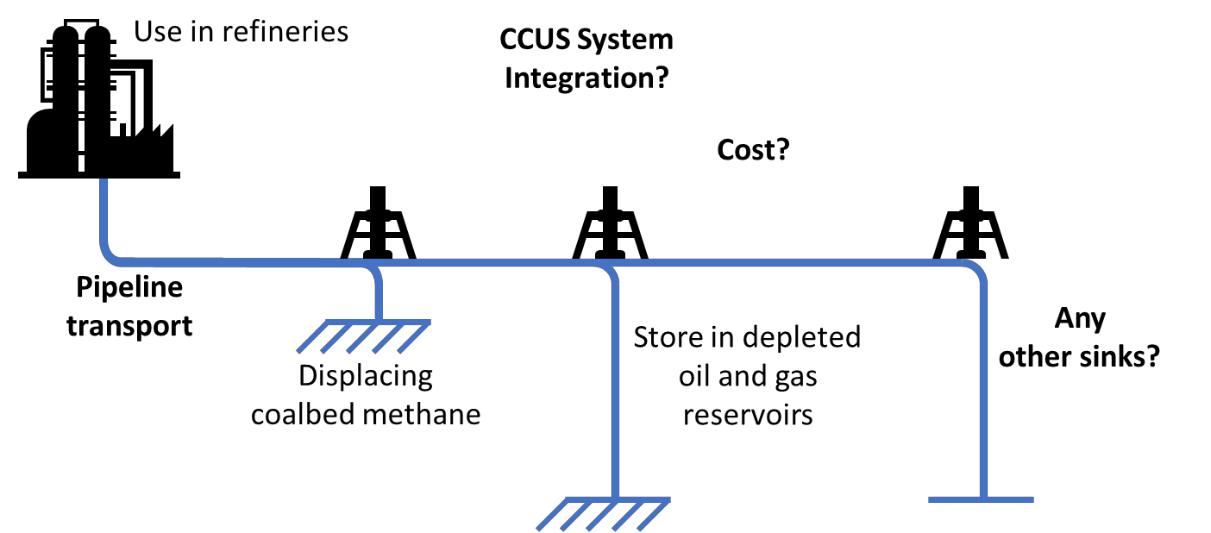
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For example, the cost is always an issue, the CO capture, compress, and transport costs CCUS is developed very fast, there are still several2 challenges that should be stressed

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potential to reduce significantly. The third issue is CCUS System Integration. An industrial which can help to reduce cost and improve efficiency, should be formed. This issue re-cluster, which can help to reduce cost and improve efficiency, should be formed. This issue quires a systematic view, other sinks that can economically utilise and store CO2 should requires a systematic view, other sinks that can economically utilise and store CO2 should be discovered, and technologies should be developed.

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**Figure 3.** Challenges of CCUS implementation.

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**3. Sustainable OGTS Development in Long-Distance Pipelines**

The long-distance pipeline is an essential part of sustainable OGTS development. With the expansion of the pipeline construction scale year by year, oil and gas will consume a lot of energy in the transmission process, resulting in energy waste. To improve the effective utilisation of energy, the energy consumption of oil and gas pipelines must be reduced. Usually, the methods to reduce energy consumption are to optimise the parameters of the pipeline system, including the pipeline diameter and pump position in the design phase,

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the pump power in the operation phase, and the energy consumption in the design and operation phases.

3.1. Design Stage

The design stage usually focused on planning pipeline routes, determining site loca-tions, and pressurisation abilities. It is important to select environmental-friendly materials for pipelines and stations, and also long-life equipment, as they don’t need to be replaced frequently. Some materials have the advantages such as low energy consumption when in the production stage. And for some warmed oil pipelines, some materials have better thermal insulation as they can keep the temperature of heated oil to reduce the energy used at stations.

Wang et al. [38] studied the problem of energy conservation and emission reduction of crude oil pipeline transportation, and optimised the design of crude oil pipelines by adopting a mathematical programming model with the minimum annual building de-preciation cost and energy consumption cost as the objective function. The locations of the pump stations and decompression stations were determined for a crude oil pipeline in northeast China, and the pipeline construction scheme with the lowest total cost was designed. In addition, the results showed that larger diameter pipes could reduce friction loss. Zhou et al. [39] studied the problem of downstream oil supply chain planning and established a nonlinear mixed integer programming model to minimise CO2 emissions and economic costs, taking into account pipeline specifications, pump station construction loca-tion and pump configurations. The Pareto optimal solution was obtained. Wang et al. [40] proposed a model for the optimal design of a large slope oil pipeline, considering the scales and locations of the pipelines, the operation plans of the pump stations, and the locations of the pressure reduction stations. A stochastic mixed integer linear programming model was adopted with the minimum cost as the objective function. The method was applied to a real case, and the minimum construction cost of the pipeline was achieved.

There are also some studies focused on the submarine pipeline. Hassan et al. [41] developed a machine-learning classifier to classify underwater soil. Through the artificial neural network analysis of soil image samples, they realised the classification of underwater soil types and established a prototype that accurately imitated the real trenching mechanism. The developed classifier was used to test three different types of soil, and then the classifier successfully identified and classified three types of soil. The results showed that compared with traditional methods, this method effectively reduced cost and saved energy.

3.2. Operating Stage

Yuan et al. [42] studied the impact of technological progress on the operation of product oil pipelines from the perspective of economy, energy conservation and carbon re-duction potential (EECP). A complete bottom-up energy consumption and CO2 calculation framework was proposed, and the price of refined oil was predicted by stepwise multiple linear regression. Applying the research contents to a real oil pipeline in Zhejiang Province, the results showed that 2/3 of the selected technical measures are economically feasible. From 2016 to 2050, the NPV, energy saving potential and carbon reduction potential of multiproduct pipelines are respectively 198.32 M CNY, 60.25% and 49.57%. Chen et al. [43] studied the issue of energy consumption in the process of crude oil pipeline transportation, proposed to use the inevitable exergy loss rate as the evaluation index, and calculated the exergy loss rate under different conditions. According to the results of orthogonal experimental analysis, the rate of exergy loss was affected by the outbound temperature, flow and outbound pressure of oil products.

Another perspective is to improve the sustainable development of long-distance pipelines through the interconnection of pipelines. In this way, existing pipelines can be fully utilised. Through the construction of some relatively cheap connecting lines, cross-regional network interconnection and utilisation can be realised. It avoids the repeated construction of pipelines and waste of facility transportation capacity.

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Yuan et al. [44] quantified the energy-environment impacts of China’s pipeline net-work interconnectivity reform on the downstream oil supply chain, introducing demand forecasting and demand redistribution into the pipeline network optimisation model. An integrated framework was developed to obtain the design scale information needed for evaluation. And a fuzzy mixed integer linear planning model was proposed to optimise the infrastructure construction scheme and supply chain operation plan while considering the uncertainty of demand. The results showed that compared with the baseline, the pipeline interconnectivity reform reduced energy consumption and CO2 emissions by 9.7–19.8% and 12.5–17.9% every year.

**4. Sustainable OGTS Development in the Supply Chain**

The supply chain is a key part of the OGTS, and sustainable developments can balance economic, environmental and social benefits. Usually, there are four transport modes applied in the oil and gas supply chain, i.e., pipeline, truck, railway, and waterway. The commonly used measures, such as reducing transport costs and improving efficiency for optimising the oil and gas supply chain, can contribute to energy-saving and emission reduction. The implementation of standardisation and resource sharing also helps the oil and gas industry to target a green and sustainable supply chain.

4.1. Economic Benefits

In current literature, many studies focused on reducing the total transport cost to reduce fuel consumption. Considering the impact of oil demand and price uncertainty on oil supply chain planning, Lima et al. [45] developed a method combining time series analysis, a scenario-based approach and multi-stage stochastic programming. The results showed that their method could deal with uncertainty correctly, reduce transportation costs, and maximise profitability. Wang et al. [46] proposed a linear integer programming model to improve the flexibility of product transportation. This model considered several route failures during transportation, and determined the backup transportation route plan. As a result, the solution achieved a 33.60% reduction in transport costs. Wang et al. [47] proposed constructing new pipelines to reduce the total operation cost for the downstream oil supply chains. A MILP model was developed, which takes transportation cost and construction cost as objective functions. The results showed that the total cost of the scheme considering new pipeline construction is the lowest compared with the scheme without new pipeline construction. Ni et al. [48] studied the elasticity of the supply chain by considering inventory strategies under extreme weather conditions. Mathematical modelling methods were used to evaluate the elasticity of the supply chain, taking the transportation cost as the objective function. The results showed that increasing the inventory by 2.67% to 14.83% can improve the elasticity of the supply chain. Appropriately increasing the elasticity of the supply chain can reduce the impact of uncertain factors on the supply system and reduce transportation cost. Lima et al. [49] used combining fuzzy parameters with integer programming to establish a mixed integer linear programming model to economically and effectively design the downstream oil supply chain. Results showed that the cost of planning the network strategically (planning by year) is lower than that of planning the network tactically (planning by month).

4.2. Environmental Issues in the Oil and Gas Supply Chain

With more concerns on environmental issues, the dual objective functions of both economic and environmental costs were considered in some recent works. Wang et al. [50] developed a P-graph model to optimise the downstream oil supply chain through emission cost relationship and performance analysis. The research results showed that a 5% reduction in greenhouse gas emissions and hazardous pollutant emissions from barges and railways could save an additional 1435 kCNY/month of environmental costs. Yuan et al. [51] studied the future development scenario of China’s downstream oil chain, analysed the impact of pipeline network reform on the energy economy and environment, and proposed a method

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combining mathematical planning with energy economy and environmental assessment to establish an integrated assessment framework. The research results showed that, compared with the vertical operating system that only considers the cost, the pipeline reform plan fully considers the environmental benefits, and improves the overall energy efficiency effectively. The annual energy consumption has been reduced by 10.70–19.70%, and the operating cost declined to 3.73–13.47%. In the latest work of Ghatee and Zarrinpoor [52], the social cost was considered together with the economic and environmental costs. In their work, a multi-objective mathematical model was developed to design the oil supply chain network, considering operating costs and environmental costs. The results showed that compared with the single objective economic model, the proposed model considered sus-tainability, reducing greenhouse gas emissions and increasing employment opportunities.

4.3. Reliability

Another issue that contributes to the sustainable development of the oil and gas sup-ply chain is reliability. A more reliable supply chain will reduce various losses, improve product arrival rate and transportation efficiency, improve social satisfaction, reduce var-ious economic costs, and reduce the environmental damage caused by failures such as leakage. Ebrahimi and Bagheri [53] designed an oil supply network including extraction, purification, storage and transportation to the multi-level market. They developed a double objective mathematical model, increased the sales profit and maximised the reliability of the processing plant. Piya et al. [54] applied integrated fuzzy interpretive structural modelling and decision-making experiment and evaluation laboratory method to analyse the driving factors of oil supply chain recovery in the COVID-19 environment. The results showed that government support and security could help restore the elasticity of the supply chain and improve its stability.

**5. LNG Technology Development**

Natural gas has an irreplaceable position in the coming decades, as it is crucial to achieving “dual carbon goals”. The natural gas demand in China keeps growing. Presently, self-produced domestic gas and imported pipeline gas supply still cannot meet the down-stream demand, so LNG terminals play a key role in this aspect. In 2021, China’s LNG import volume is about 80 Mt. If 50% of LNG cold energy can be recovered, China’s LNG cold energy availability will be approximately 8 billion kWh. Recently, there are two new LNG terminal projects got approved and terminals will be constructed in Zhoushan, which is a coastal city located in the east of China. These two new terminals will receive LNG of about 13 Mt per year. The effect of energy conservation and environmental protection, and relatively large economic, environmental, and social benefits can also be achieved.

There are many studies focused on LNG cold energy utilisation. Ouyang et al. [55] developed an LNG-fired power plant which utilised the LNG cold energy for power generation. With this new system, the net work generated, thermal efficiency and exergy efficiency have 28.9%, 32.2% and 16.3% increase. This project has good economic benefits, as it has only 1.85 payback years. It also has a total CO2 capture capacity of 278 kt per year. Kim et al. [56] proposed a novel cryogenic CCS process that utilise LNG cold energy to reduce heat loss of power generation, and to increase the efficiency of CCS. Using their new process, the CO2 capture rate can be as high as 99.93%. Aryanfar et al. [57] developed a novel recovery single-flash geothermal cycle (SFGC) for a power plant coupled with an LNG heat sink. Through the analysis, the energy efficiency of the SFGC increases to 0.3863 and 0.4066 for two types of working fluids.

There are some studies focused on Heat Integration for LNG. Shaikh et al. [58] devel-oped a Pinch Analysis based method and studied the Heat Integration for the hot section of the LNG process. The Tri-Ethylene Glycol Dehydration and Condensate stabilisation units were integrated. Good environmental benefits were achieved, as 18.83% and 21.37% of energy consumption for heating and cooling were reduced, together with 316.2 t/d for carbon emissions reduction. Chen et al. [59] studied the heat exchange of LNG and N2 by

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Pinch Analysis. The influence of the air separation unit cooled by LNG cryogenic energy (CEASU) was also evaluated. The results showed that 5% to 12 % of energy consumption could be reduced by the proposed CEASU.

The LNG tank construction, management, and extended cold energy utilisation are all part of the study subjects of OGTS engineering. Lots of efforts should be input into promoting the new development of LNG-related technologies and accelerating the steps of achieving “dual carbon goals”.

**6. Energy Structure**

The current energy consumption structure is not environmental-friendly in most sectors of the OGTS industry. For example, the oil field mainly uses electricity from the power grid to meet its energy needs. It does not fully use renewable energy, resulting in high carbon emissions caused by oil field production activities. Taking the oil field as an example, as it has wide space for constructing photovoltaic panels or wind turbines, the potential for utilising these renewable sources is quite high.

It is necessary to adjust the energy structure, increase the proportion of clean energy, and achieve the purpose of reducing carbon emissions. Currently, the existing research mainly uses renewable energy, including wind and solar energy, to integrate with the original natural gas and external power grid to provide power and heat energy for oil-field production and life by establishing a distributed energy system. Li et al. [60] devel-oped a multi-objective mathematical model to determine the optimal facility capacities of a distributed energy system. The aims included annual cost and carbon emission. The developed distributed energy system has energy sources, including solar, wind, crude oil and natural gas. The total cost and carbon emission were reduced by 14.6% and 1360 t by ad-justing the energy structure on floating production storage and offloading. Zhang et al. [61] integrated wind power into an oil and gas production platform to reduce operating costs and carbon footprints. Scenarios were compared to show the economic and environmental performance of traditional energy systems, and distributed energy systems with and with-out wind energy. The case results showed that 39.91% of carbon emissions and 2.57% of the total annual cost could be reduced when wind energy was integrated. Another in-teresting paper that focused on the energy structure in oil and field was developed by Zou et al. [62], who considered hydrogen and natural gas, together with the wind, to form a wind–hydrogen–natural gas system for offshore oil and gas field development. The performances of the traditional energy system, wind-natural gas system, and the newly proposed three energy-integrated systems were compared. Significant economic benefits were reported in the case of Bohai Bay.

Huang et al. [63] studied the relationship between energy input and output, carbon emissions and water use in oil and gas exploitation. Taking Daqing and Shengli Oilfields as examples, the energy return evaluation model of energy, carbon and water investment in oil and gas resource development was constructed. The results showed that the energy return evaluation method considering the input of energy, carbon and water is more comprehensive than only considering the input and output of energy, and can evaluate the development of oil and gas resources more effectively.

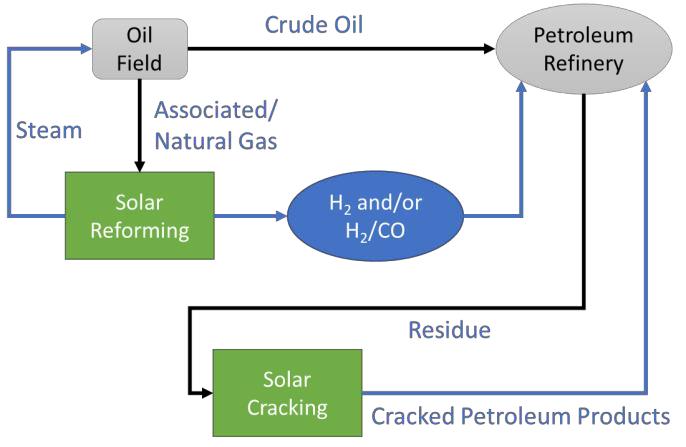
6.1. Solar Energy

Some studies have proposed several methods for utilising solar energy in oil and gas fields. Abd et al. [64] proposed an integrated energy system for solar-enhanced oil recovery. The generated energy can be used for power generation, artificial lift, and steam injection under high temperatures through the concentrated solar power generation technology of solar towers. Through this method, the energy efficiency and exergy efficiency were greatly improved, which were 84% and 33.7%. One potential scheme for producing hydrogen or synthesis gas near an oil field using solar reforming is illustrated in Figure 4.

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**Figure 4.** Hydrogen or synthesis gas production using solar reforming for an oilfield [65].

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6.2. Geothermal Utilisation

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tion sites to geothermal plants; one example is Soultz-sous-Forêts [67]. Singh et al. [6 developed a field-scale hydro-thermal model to study the heat extraction potential of

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et al. [69] proposed2 a mathematical model for an integrated energy system with a supe in the high water cut stage at a temperature close to 140 C. The output power of the

critical CO2 power cycle, to recover the heat of hot water obtained from oil fields in th supercritical CO2 power cycle was used to run the compressor of the ejector expansion

high water cut stage at a temperature close to 140 °C. The output power of the supercritic CO2 refrigeration cycle. The Humidification-dehumidification desalination unit partially

CO2 power cycle was used to run the compressor of the ejector expansion CO2 refriger utilised the waste heat of CO2 circulation. The proposed energy system can partially

tion cycle. The Humidification-dehumidification desalination unit partially utilised th meet the energy demand and freshwater supply, with a payback period varying from

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Site Profiles were applied to visualise the integration process. An example shows that

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**7.**cycle**Conclusions**wereoptimised**andFuture**. **Directions**

With the fast development of low-carbon and sustainable measures implemented in oil and gas transport and storage engineering, this industry is entering a new era. Together with the increase in natural gas consumption percentage, acceleration of oil and gas trunk pipelines, regional branch pipelines and gas distribution pipelines construction, the improvement of the LNG terminals and their supporting export pipelines arrangement, and the promotion of oil and gas pipelines interconnection, the future of the OGTS would be bright. This paper reviews the developments in the four main fields of OGTS, i.e., oil

* gas fields, long-distance pipeline, oil & gas supply chain, and LNG technology, as well as the energy structure changing studies that related to OGTS engineering, to show the latest studies and technologies that contribute to the sustainability. Results showed that energy consumption and CO2 emissions are reduced through optimisation methods, energy structure changing, and new equipment and facilities.

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Besides, many research opportunities exist in the sustainable developments of OGTS fields, especially developing advanced and more detailed models to reflect better the real situations and scenarios of the OGTS issues, integrating modern technologies in the processes for efficiency improvements, and efficient algorithms to solve large-scale network problems. For the sustainable development goal, not only economic and environmental issues should be considered, but also a harmonious relationship between OGTS engineering and human should be stressed.

In the future, it is urgent to formulate a low-carbon development plan for every in-volved enterprise, to determine the future direction for sustainable development. Measures such as establishing and improving the carbon emission management system, participating in the carbon trading market, and increasing the investment of low-carbon related studies, would contribute to achieving a sustainable and low-carbon transformation.

**Funding:** This research was funded by “Pioneer” and “Leading Goose” R&D Program of Zhejiang (2023C04048), Scientific Research Fund of Zhejiang Provincial Education Department (Y202250605), and Science Foundation of Zhejiang Ocean University (11025092122).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data sharing not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

**References**

1. Liao, Q.; Liang, Y.; Tu, R.; Huang, L.; Zheng, J.; Wang, G.; Zhang, H. Innovations of Carbon-Neutral Petroleum Pipeline: A Review. Energy Rep. **2022**, 8, 13114–13128. [[CrossRef](http://doi.org/10.1016/j.egyr.2022.09.187)]
2. Huang, L.; Liao, Q.; Yan, J.; Liang, Y.; Zhang, H. Carbon Footprint of Oil Products Pipeline Transportation. Sci. Total Environ. **2021**, 783, 146906. [[CrossRef](http://doi.org/10.1016/j.scitotenv.2021.146906)] [[PubMed](http://www.ncbi.nlm.nih.gov/pubmed/33866177)]
3. Song, X.; Qu, D.; Zou, C. Low Cost Development Strategy for Oilfields in China under Low Oil Prices. Pet. Explor. Dev. **2021**, 48, 1007–1018. [[CrossRef](http://doi.org/10.1016/S1876-3804(21)60085-X)]
4. Wang, B.; Liang, Y.; Yuan, M. Water Transport System Optimisation in Oilfields: Environmental and Economic Benefits. J. Clean. Prod. **2019**, 237, 117768. [[CrossRef](http://doi.org/10.1016/j.jclepro.2019.117768)]
5. Zhou, J.; Fu, T.; Wu, K.; Zhao, Y.; Feng, L.; Liang, G. Optimization Design of Multi-Gathering Mode for the Surface System in Coalbed Methane Field. Petroleum **2022**. [[CrossRef](http://doi.org/10.1016/j.petlm.2022.01.001)]
6. Montagna, A.F.; Cafaro, D.C.; Grossmann, I.E.; Burch, D.; Shao, Y.; Wu, X.-H.; Furman, K. Pipeline Network Design for Gathering Unconventional Oil and Gas Production Using Mathematical Optimization. Optim. Eng. **2021**. [[CrossRef](http://doi.org/10.1007/s11081-021-09695-z)]
7. Almedallah, M.K.; Branch, G.; Walsh, S.D.C. Combined Well Path, Submarine Pipeline Network, Route and Flow Rate Optimiza-tion for Shallow-Water Offshore Fields. Appl. Ocean Res. **2020**, 105, 102396. [[CrossRef](http://doi.org/10.1016/j.apor.2020.102396)]
8. Zheng, T.; Liang, Y.; Wang, B.; Sun, H.; Zheng, J.; Li, D.; Chen, Y.; Shao, L.; Zhang, H. A Two-Stage Improved Genetic Algorithm-Particle Swarm Optimization Algorithm for Optimizing the Pressurization Scheme of Coal Bed Methane Gathering Networks. J. Clean. Prod. **2019**, 229, 941–955. [[CrossRef](http://doi.org/10.1016/j.jclepro.2019.04.348)]
9. Zhao, Y.; Yao, L.; Liu, L.; Xu, Y. Optimization of Energy Saving Gathering and Transportation Mode in a Block of Tahe Oilfield. Case Stud. Therm. Eng. **2019**, 13, 100378. [[CrossRef](http://doi.org/10.1016/j.csite.2018.100378)]
10. Wang, B.; Liang, Y.; Zheng, J.; Lei, T.; Yuan, M.; Zhang, H. A Methodology to Restructure a Pipeline System for an Oilfield in the Mid to Late Stages of Development. Comput. Chem. Eng. **2018**, 115, 133–140. [[CrossRef](http://doi.org/10.1016/j.compchemeng.2018.04.008)]
11. Bai, Y.; Hou, J.; Liu, Y.; Zhao, D.; Bing, S.; Xiao, W.; Zhao, W. Energy-Consumption Calculation and Optimization Method of Integrated System of Injection-Reservoir-Production in High Water-Cut Reservoir. Energy **2022**, 239, 121961. [[CrossRef](http://doi.org/10.1016/j.energy.2021.121961)]
12. Allahyarzadeh-Bidgoli, A.; Dezan, D.J.; Salviano, L.O.; de Oliveira Junior, S.; Yanagihara, J.I. Lifetime Sensitivity Analysis of FPSO Operating Parameters on Energy Consumption and Overall Oil Production in a Pre-Salt Oil Field. Chem. Eng. Commun. **2020**, 207, 1483–1507. [[CrossRef](http://doi.org/10.1080/00986445.2019.1659247)]
13. Zhang, Y.; Wang, B.; Liang, Y.; Yuan, M.; Varbanov, P.S.; Klemeš, J.J. A Method for Simultaneous Retrofit of Heat Exchanger Networks and Tower Operations for an Existing Natural Gas Purification Process. e-Prime—Adv. Electr. Eng. Electron. Energy **2021**, 1, 100019. [[CrossRef](http://doi.org/10.1016/j.prime.2021.100019)]
14. Wang, B.; Liang, Y.; Zheng, T.; Yuan, M.; Zhang, H. Multi-Objective Site Selection Optimization of the Gas-Gathering Station Using NSGA-II. Process Saf. Environ. Prot. **2018**, 119, 350–359. [[CrossRef](http://doi.org/10.1016/j.psep.2018.08.017)]
15. Li, J.; Guo, Y.; Zhang, X.; Fu, Z. Using Hybrid Machine Learning Methods to Predict and Improve the Energy Consumption Efficiency in Oil and Gas Fields. Mob. Inf. Syst. **2021**, 2021, e5729630. [[CrossRef](http://doi.org/10.1155/2021/5729630)]

|  |  |
| --- | --- |
| Energies **2023**, 16, 1775 | 14 of 16 |
|  |  |

1. Amakiri, K.T.; Canon, A.R.; Molinari, M.; Angelis-Dimakis, A. Review of Oilfield Produced Water Treatment Technologies. Chemosphere **2022**, 298, 134064. [[CrossRef](http://doi.org/10.1016/j.chemosphere.2022.134064)] [[PubMed](http://www.ncbi.nlm.nih.gov/pubmed/35240151)]
2. Ghafoori, S.; Omar, M.; Koutahzadeh, N.; Zendehboudi, S.; Malhas, R.N.; Mohamed, M.; Al-Zubaidi, S.; Redha, K.; Baraki, F.; Mehrvar, M. New Advancements, Challenges, and Future Needs on Treatment of Oilfield Produced Water: A State-of-the-Art Review. Sep. Purif. Technol. **2022**, 289, 120652. [[CrossRef](http://doi.org/10.1016/j.seppur.2022.120652)]
3. Samuel, O.; Othman, M.H.D.; Kamaludin, R.; Sinsamphanh, O.; Abdullah, H.; Puteh, M.H.; Kurniawan, T.A.; Li, T.; Ismail, A.F.; Rahman, M.A.; et al. Oilfield-Produced Water Treatment Using Conventional and Membrane-Based Technologies for Beneficial Reuse: A Critical Review. J. Environ. Manag. **2022**, 308, 114556. [[CrossRef](http://doi.org/10.1016/j.jenvman.2022.114556)]
4. Liu, Y.; Li, Y.; Lu, H.; Pan, Z.; Dai, P.; Sun, G.; Yang, Q. A Full-Scale Process for Produced Water Treatment on Offshore Oilfield: Reduction of Organic Pollutants Dominated by Hydrocarbons. J. Clean. Prod. **2021**, 296, 126511. [[CrossRef](http://doi.org/10.1016/j.jclepro.2021.126511)]
5. Wu, J.; Zeng, R.J.; Zhang, F.; Yuan, Z. Application of Iron-Crosslinked Sodium Alginate for Efficient Sulfide Control and Reduction of Oilfield Produced Water. Water Res. **2019**, 154, 12–20. [[CrossRef](http://doi.org/10.1016/j.watres.2019.01.030)]
6. de Carvalho Neto, S.L.; Toledo Viviani, J.C.; Weschenfelder, S.E.; da Cunha, M.D.F.R.; Orlando Junior, A.E.; dos Santos Costa, B.R.; Mazur, L.P.; Marinho, B.A.; da Silva, A.; de Souza, A.A.U.; et al. Evaluation of Petroleum as Extractor Fluid in Liquid-Liquid Extraction to Reduce the Oil and Grease Content of Oilfield Produced Water. Process Saf. Environ. Prot. **2022**, 161, 263–272. [[CrossRef](http://doi.org/10.1016/j.psep.2022.03.041)]
7. Esmaeilnezhad, E.; Choi, H.J. Polyindole Nanoparticle-Based Electrorheological Fluid and Its Green and Clean Future Potential Conformance Control Technique to Oil Fields. J. Clean. Prod. **2019**, 231, 1218–1225. [[CrossRef](http://doi.org/10.1016/j.jclepro.2019.05.341)]
8. Cao, X.; Gao, X.; Zheng, K.; Wu, S.; Wu, Y.; Meng, G.; Hu, Z.; Niu, Q.; Su, J. Efficient Pollutants Removal and Microbial Flexibility under High-Salt Gradient of an Oilfield Wastewater Treatment System. Sci. Total Environ. **2022**, 823, 153619. [[CrossRef](http://doi.org/10.1016/j.scitotenv.2022.153619)] [[PubMed](http://www.ncbi.nlm.nih.gov/pubmed/35124032)]
9. Chen, T.; Zheng, P.; Zhang, Y.; Dong, C.; Han, G.; Li, H.; Yang, X.; Liu, Y.; Sun, J.; Li, H.; et al. Characteristics and Formation Mechanisms of Atmospheric Carbonyls in an Oilfield Region of Northern China. Atmos. Environ. **2022**, 274, 118958. [[CrossRef](http://doi.org/10.1016/j.atmosenv.2022.118958)]
10. Xin, Y.; Zhang, Y.; Xue, P.; Wang, K.; Adu, E.; Tontiwachwuthikul, P. The Optimization and Thermodynamic and Economic Estimation Analysis for CO2 Compression-Liquefaction Process of CCUS System Using LNG Cold Energy. Energy **2021**, 236, 121376. [[CrossRef](http://doi.org/10.1016/j.energy.2021.121376)]
11. Leonzio, G.; Bogle, D.; Foscolo, P.U.; Zondervan, E. Optimization of CCUS Supply Chains in the UK: A Strategic Role for Emissions Reduction. Chem. Eng. Res. Des. **2020**, 155, 211–228. [[CrossRef](http://doi.org/10.1016/j.cherd.2020.01.002)]
12. El-kaseeh, G.; Will, R.; Balch, R.; Grigg, R. Multi-Scale Seismic Measurements for CO2 Monitoring in an EOR/CCUS Project. Energy Procedia **2017**, 114, 3656–3670. [[CrossRef](http://doi.org/10.1016/j.egypro.2017.03.1497)]
13. Andersen, P.Ø.; Brattekås, B.; Zhou, Y.; Nadeau, P.; Nermoen, A.; Yu, Z.; Fjelde, I.; Oelkers, E. Carbon Capture Utilization and Storage (CCUS) in Tight Gas and Oil Reservoirs. J. Nat. Gas Sci. Eng. **2020**, 81, 103458. [[CrossRef](http://doi.org/10.1016/j.jngse.2020.103458)]
14. Suicmez, V.S. Feasibility Study for Carbon Capture Utilization and Storage (CCUS) in the Danish North Sea. J. Nat. Gas Sci. Eng. **2019**, 68, 102924. [[CrossRef](http://doi.org/10.1016/j.jngse.2019.102924)]
15. Fukai, I.; Mishra, S.; Pasumarti, A. Technical and Economic Performance Metrics for CCUS Projects: Example from the East Canton Consolidated Oil Field, Ohio, USA. Energy Procedia **2017**, 114, 6968–6979. [[CrossRef](http://doi.org/10.1016/j.egypro.2017.03.1838)]
16. Li, P.; Yi, L.; Liu, X.; Hu, G.; Lu, J.; Zhou, D.; Hovorka, S.; Liang, X. Screening and Simulation of Offshore CO2-EOR and Storage: A Case Study for the HZ21-1 Oilfield in the Pearl River Mouth Basin, Northern South China Sea. Int. J. Greenh. Gas Control **2019**, 86, 66–81. [[CrossRef](http://doi.org/10.1016/j.ijggc.2019.04.015)]
17. Lv, G.; Li, Q.; Wang, S.; Li, X. Key Techniques of Reservoir Engineering and Injection–Production Process for CO2 Flooding in China’s SINOPEC Shengli Oilfield. J. CO2 Util. **2015**, 11, 31–40. [[CrossRef](http://doi.org/10.1016/j.jcou.2014.12.007)]
18. Yang, L.; Xu, M.; Yang, Y.; Fan, J.; Zhang, X. Comparison of Subsidy Schemes for Carbon Capture Utilization and Storage (CCUS) Investment Based on Real Option Approach: Evidence from China. Appl. Energy **2019**, 255, 113828. [[CrossRef](http://doi.org/10.1016/j.apenergy.2019.113828)]
19. Jiang, K.; Ashworth, P. The Development of Carbon Capture Utilization and Storage (CCUS) Research in China: A Bibliometric Perspective. Renew. Sustain. Energy Rev. **2021**, 138, 110521. [[CrossRef](http://doi.org/10.1016/j.rser.2020.110521)]
20. Li, Q.; Liu, G.; Leamon, G.; Liu, L.-C.; Cai, B.; Chen, Z.-A. A National Survey of Public Awareness of the Environmental Impact and Management of CCUS Technology in China. Energy Procedia **2017**, 114, 7237–7244. [[CrossRef](http://doi.org/10.1016/j.egypro.2017.03.1854)]
21. Li, Q.; Chen, Z.A.; Zhang, J.-T.; Liu, L.-C.; Li, X.C.; Jia, L. Positioning and Revision of CCUS Technology Development in China. Int. J. Greenh. Gas Control **2016**, 46, 282–293. [[CrossRef](http://doi.org/10.1016/j.ijggc.2015.02.024)]
22. Yang, W.; Peng, B.; Wu, M.; Li, J.; Ni, P. Evaluation for CO2 Geo-Storage Potential and Suitability in Dagang Oilfield. Energy Procedia **2016**, 86, 41–46. [[CrossRef](http://doi.org/10.1016/j.egypro.2016.01.005)]
23. Wang, B.; Zhang, H.; Yuan, M.; Wang, Y.; Menezes, B.C.; Li, Z.; Liang, Y. Sustainable Crude Oil Transportation: Design Optimiza-tion for Pipelines Considering Thermal and Hydraulic Energy Consumption. Chem. Eng. Res. Des. **2019**, 151, 23–39. [[CrossRef](http://doi.org/10.1016/j.cherd.2019.07.034)]
24. Zhou, X.; Zhang, H.; Xin, S.; Yan, Y.; Long, Y.; Yuan, M.; Liang, Y. Future Scenario of China’s Downstream Oil Supply Chain: Low Carbon-Oriented Optimization for the Design of Planned Multi-Product Pipelines. J. Clean. Prod. **2020**, 244, 118866. [[CrossRef](http://doi.org/10.1016/j.jclepro.2019.118866)]
25. Wang, B.; Yuan, M.; Yan, Y.; Yang, K.; Zhang, H.; Liang, Y. Optimal Design of an Oil Pipeline with a Large-Slope Section. Eng. Optim. **2019**, 51, 1480–1494. [[CrossRef](http://doi.org/10.1080/0305215X.2018.1525710)]

|  |  |
| --- | --- |
| Energies **2023**, 16, 1775 | 15 of 16 |
|  |  |

1. Hassan, K.A.; Elgendi, E.O.; Shehata, A.S.; Elmasry, M.I. Energy Saving and Environment Protection Solution for the Submarine Pipelines Based on Deep Learning Technology. Energy Rep. **2022**, 8, 1261–1274. [[CrossRef](http://doi.org/10.1016/j.egyr.2022.07.127)]
2. Yuan, M.; Zhang, H.; Long, Y.; Shen, R.; Wang, B.; Liang, Y. Economic, Energy-Saving and Carbon-Abatement Potential Forecast of Multiproduct Pipelines: A Case Study in China. J. Clean. Prod. **2019**, 211, 1209–1227. [[CrossRef](http://doi.org/10.1016/j.jclepro.2018.11.144)]
3. Cheng, Q.; Zheng, A.; Yang, L.; Pan, C.; Sun, W.; Liu, Y. Studies on Energy Consumption of Crude Oil Pipeline Transportation Process Based on the Unavoidable Exergy Loss Rate. Case Stud. Therm. Eng. **2018**, 12, 8–15. [[CrossRef](http://doi.org/10.1016/j.csite.2018.02.005)]
4. Yuan, M.; Zhang, H.; Wang, B.; Zhang, Y.; Zhou, X.; Liang, Y. Future Scenario of China’s Downstream Oil Reform: Improving the Energy-Environmental Efficiency of the Pipeline Networks through Interconnectivity. Energy Policy **2020**, 140, 111403. [[CrossRef](http://doi.org/10.1016/j.enpol.2020.111403)]
5. Lima, C.; Relvas, S.; Barbosa-Póvoa, A. Stochastic Programming Approach for the Optimal Tactical Planning of the Downstream Oil Supply Chain. Comput. Chem. Eng. **2018**, 108, 314–336. [[CrossRef](http://doi.org/10.1016/j.compchemeng.2017.09.012)]
6. Wang, B.; Klemeš, J.J.; Yu, X.; Qiu, R.; Zheng, J.; Lin, Y.; Zhu, B. Planning of a Flexible Refined Products Transportation Network in Response to Emergencies. J. Pipeline Sci. Eng. **2022**. [[CrossRef](http://doi.org/10.1016/j.jpse.2021.12.004)]
7. Wang, B.; Liang, Y.; Zheng, T.; Yuan, M.; Zhang, H. Optimisation of a Downstream Oil Supply Chain with New Pipeline Route Planning. Chem. Eng. Res. Des. **2019**, 145, 300–313. [[CrossRef](http://doi.org/10.1016/j.cherd.2019.03.009)]
8. Ni, W.; Liang, Y.; Li, Z.; Liao, Q.; Cai, S.; Wang, B.; Zhang, H.; Wang, Y. Resilience Assessment of the Downstream Oil Supply Chain Considering the Inventory Strategy in Extreme Weather Events. Comput. Chem. Eng. **2022**, 163, 107831. [[CrossRef](http://doi.org/10.1016/j.compchemeng.2022.107831)]
9. Lima, C.; Relvas, S.; Barbosa-Póvoa, A. Designing and Planning the Downstream Oil Supply Chain under Uncertainty Using a Fuzzy Programming Approach. Comput. Chem. Eng. **2021**, 151, 107373. [[CrossRef](http://doi.org/10.1016/j.compchemeng.2021.107373)]
10. Wang, B.; Fan, Y.V.; Chin, H.H.; Klemeš, J.J.; Liang, Y. Emission-Cost Nexus Optimisation and Performance Analysis of Downstream Oil Supply Chains. J. Clean. Prod. **2020**, 266, 121831. [[CrossRef](http://doi.org/10.1016/j.jclepro.2020.121831)]
11. Yuan, M.; Zhang, H.; Wang, B.; Shen, R.; Long, Y.; Liang, Y. Future Scenario of China’s Downstream Oil Supply Chain: An Energy, Economy and Environment Analysis for Impacts of Pipeline Network Reform. J. Clean. Prod. **2019**, 232, 1513–1528. [[CrossRef](http://doi.org/10.1016/j.jclepro.2019.05.340)]
12. Ghatee, A.; Zarrinpoor, N. Designing an Oil Supply Chain Network Considering Sustainable Development Paradigm and Uncertainty. Chem. Eng. Res. Des. **2022**, 184, 692–723. [[CrossRef](http://doi.org/10.1016/j.cherd.2022.06.026)]
13. Ebrahimi, S.B.; Bagheri, E. Optimizing Profit and Reliability Using a Bi-Objective Mathematical Model for Oil and Gas Supply Chain under Disruption Risks. Comput. Ind. Eng. **2022**, 163, 107849. [[CrossRef](http://doi.org/10.1016/j.cie.2021.107849)]
14. Piya, S.; Shamsuzzoha, A.; Khadem, M. Analysis of Supply Chain Resilience Drivers in Oil and Gas Industries during the COVID-19 Pandemic Using an Integrated Approach. Appl. Soft Comput. **2022**, 121, 108756. [[CrossRef](http://doi.org/10.1016/j.asoc.2022.108756)] [[PubMed](http://www.ncbi.nlm.nih.gov/pubmed/35369123)]
15. Ouyang, T.; Tan, J.; Wu, W.; Xie, S.; Li, D. Energy, Exergy and Economic Benefits Deriving from LNG-Fired Power Plant: Cold Energy Power Generation Combined with Carbon Dioxide Capture. Renew. Energy **2022**, 195, 214–229. [[CrossRef](http://doi.org/10.1016/j.renene.2022.06.033)]
16. Kim, Y.; Lee, J.; Cho, H.; Kim, J. Novel Cryogenic Carbon Dioxide Capture and Storage Process Using LNG Cold Energy in a Natural Gas Combined Cycle Power Plant. Chem. Eng. J. **2022**, 140980. [[CrossRef](http://doi.org/10.2139/ssrn.4250700)]
17. Aryanfar, Y.; Mohtaram, S.; García Alcaraz, J.L.; Sun, H. Energy and Exergy Assessment and a Competitive Study of a Two-Stage ORC for Recovering SFGC Waste Heat and LNG Cold Energy. Energy **2023**, 264, 126191. [[CrossRef](http://doi.org/10.1016/j.energy.2022.126191)]
18. Shaikh, A.A.; AlNouss, A.; Al-Ansari, T. A Heat Integration Case Study for the Dehydration and Condensate Stabilization Units in LNG Plants for Economic and Energy Savings. Comput. Chem. Eng. **2022**, 168, 108062. [[CrossRef](http://doi.org/10.1016/j.compchemeng.2022.108062)]
19. Chen, S.; Xu, J.; Dong, X.; Zhang, H.; Gao, Q.; Tan, C. Pinch Point Analysis of Heat Exchange for Liquid Nature Gas (LNG) Cryogenic Energy Using in Air Separation Unit. Int. J. Refrig. **2018**, 90, 264–276. [[CrossRef](http://doi.org/10.1016/j.ijrefrig.2017.12.015)]
20. Li, Z.; Zhang, H.; Meng, J.; Long, Y.; Yan, Y.; Li, M.; Huang, Z.; Liang, Y. Reducing Carbon Footprint of Deep-Sea Oil and Gas Field Exploitation by Optimization for Floating Production Storage and Offloading. Appl. Energy **2020**, 261, 114398. [[CrossRef](http://doi.org/10.1016/j.apenergy.2019.114398)]
21. Zhang, Q.; Zhang, H.; Yan, Y.; Yan, J.; He, J.; Li, Z.; Shang, W.; Liang, Y. Sustainable and Clean Oilfield Development: How Access to Wind Power Can Make Offshore Platforms More Sustainable with Production Stability. J. Clean. Prod. **2021**, 294, 126225. [[CrossRef](http://doi.org/10.1016/j.jclepro.2021.126225)]
22. Zou, X.; Qiu, R.; Yuan, M.; Liao, Q.; Yan, Y.; Liang, Y.; Zhang, H. Sustainable Offshore Oil and Gas Fields Development: Techno-Economic Feasibility Analysis of Wind–Hydrogen–Natural Gas Nexus. Energy Rep. **2021**, 7, 4470–4482. [[CrossRef](http://doi.org/10.1016/j.egyr.2021.07.035)]
23. Huang, C.; Gu, B.; Chen, Y.; Tan, X.; Feng, L. Energy Return on Energy, Carbon, and Water Investment in Oil and Gas Resource Extraction: Methods and Applications to the Daqing and Shengli Oilfields. Energy Policy **2019**, 134, 110979. [[CrossRef](http://doi.org/10.1016/j.enpol.2019.110979)]
24. Abd, A.S.; Abushaikha, A.; Bicer, Y. A Comprehensive Thermodynamic Analysis of an Integrated Solar Enhanced Oil Recovery System for Applications in Heavy Oil Fields. Energy Convers. Manag. **2022**, 253, 115161. [[CrossRef](http://doi.org/10.1016/j.enconman.2021.115161)]
25. Absi Halabi, M.; Al-Qattan, A.; Al-Otaibi, A. Application of Solar Energy in the Oil Industry—Current Status and Future Prospects. Renew. Sustain. Energy Rev. **2015**, 43, 296–314. [[CrossRef](http://doi.org/10.1016/j.rser.2014.11.030)]
26. Alimonti, C.; Soldo, E.; Scrocca, D. Looking Forward to a Decarbonized Era: Geothermal Potential Assessment for Oil & Gas Fields in Italy. Geothermics **2021**, 93, 102070. [[CrossRef](http://doi.org/10.1016/j.geothermics.2021.102070)]
27. Mahmoodpour, S.; Singh, M.; Mahyapour, R.; Tangirala, S.K.; Bär, K.; Sass, I. Numerical Simulation of Thermo-Hydro-Mechanical Processes at Soultz-Sous-Forêts. Energies **2022**, 15, 9285. [[CrossRef](http://doi.org/10.3390/en15249285)]
28. Singh, M.; Mahmoodpour, S.; Ershadnia, R.; Soltanian, M.R.; Sass, I. Comparative Study on Heat Extraction from Soultz-Sous-Forêts Geothermal Field Using Supercritical Carbon Dioxide and Water as the Working Fluid. Energy **2023**, 266, 126388. [[CrossRef](http://doi.org/10.1016/j.energy.2022.126388)]

|  |  |
| --- | --- |
| Energies **2023**, 16, 1775 | 16 of 16 |
|  |  |

1. Sahana, C.; De, S.; Mondal, S. Integration of CO2 Power and Refrigeration Cycles with a Desalination Unit to Recover Geothermal Heat in an Oilfield. Appl. Therm. Eng. **2021**, 189, 116744. [[CrossRef](http://doi.org/10.1016/j.applthermaleng.2021.116744)]
2. Wang, B.; Klemeš, J.J.; Varbanov, P.S.; Shahzad, K.; Kabli, M.R. Total Site Heat Integration Benefiting from Geothermal Energy for Heating and Cooling Implementations. J. Environ. Manag. **2021**, 290, 112596. [[CrossRef](http://doi.org/10.1016/j.jenvman.2021.112596)]

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