The Future of Contracts in the Energy Sector: A Legal Analysis of Smart Contracts within the Oil Industry

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Abstract

This paper investigates the legal challenges and potentialities arising from the implementation of smart contracts and blockchain technology in the oil industry. The research analyzes how these instruments may contribute to enhancing transparency, efficiency, and promptness in access to commercial data, as well as to simplifying regulatory compliance processes. Nevertheless, the study also examines the inherent limitations and risks of their adoption, including difficulties in contractual interpretation, the rigidity of pre-programmed rules, incompatibility with open-ended clauses, and the challenge of adapting to unforeseen circumstances.

Keywords: Smartcontracts; Blockchain; Oil Industry; Petroleum Contracts; Upstream

1. Introduction

The digital revolution has profoundly transformed legal and economic relations, imposing new paradigms on the manner in which contracts are conceived, executed, and supervised. Among the most relevant innovations in this field are smart contracts, digital instruments based on blockchain technology that enable the automatic execution of contractual clauses according to pre-programmed conditions. The oil industry, characterized by highly complex operations, multiple stakeholders, and significant financial risks, emerges as a particularly suitable domain for the application of smart contracts. The integration of this technology can enhance efficiency, reduce administrative costs, mitigate fraud, and ensure greater transparency in exploration, transportation, and commercialization processes. Conversely, the adoption of smart contracts in this sector encounters structural legal obstacles that go beyond purely technical challenges. The rigid, deterministic, and self-executing nature of these instruments often clashes with foundational principles of classical contract law, such as adaptation to unforeseen circumstances, interpretation in accordance with good faith, and the preservation of contractual balance.

The application of smart contracts in the oil industry proves particularly challenging in long-term agreements subject to geopolitical volatility, regulatory developments, and state intervention, where open clauses and renegotiation mechanisms are indispensable. Accordingly, this research undertakes a legal analysis of the implementation of smart contracts within the oil industry. Such analysis is essential to understand how the law may adapt to this new reality, balancing the promotion of innovation with the preservation of fundamental principles of contractual justice and legal certainty. This article aims to examine the advantages, limitations, and legal implications of this technology, thereby contributing to the debate on the future of contracts in the context of the digital economy and the global energy transition.

2. A Structural Analysis of Smart Contracts and Blockchain

In this section, provides a comprehensive analysis of the operation of smart contracts (2.1.) and blockchain technology (2.2), with the purpose of elucidating their fundamental characteristics and underlying principles.

2.1. Analysis of Smartcontracts

In recent years, the advance of distributed technologies, particularly blockchains, has facilitated a profound evolution in traditional methods of contracting, performance, and enforcement. Within this context, the concept of the smart contract has emerged, its intellectual genesis most commonly attributed to Nick Szabo. Szabo defines these instruments as "a computerized transaction protocol that executes the terms of a contract." Concerning their underlying objectives, he explains that "the general objectives of smart contracts design are to satisfy common contractual conditions (such as payment terms, liens, confidentiality, and even enforcement), minimize exceptions both malicious and accidental, and minimize the need for trusted intermediaries.

Related economic goals include lowering fraud and loss, arbitration and enforcement costs, and other transaction costs[1]." Smart contracts entail the automation of the parties mutual assent by converting their agreement into code. This code encapsulates their pre-established conditions and is designed for self-execution, operating electronically without requiring intervention from a third party. This autonomous function is intrinsic to the technology, as both the genesis and performance of the contract occur natively within the Blockchain network[2]. Smart contracts are written in a specific, deterministic language distinct from human language subsequently referred to as machine language, software, or code[3]. This enables a computer, device, or machine to process and, thereby, give effect to their stipulated outcomes[4]. The use of machine language to configure the agreement, inclusive of all its subsequent considerations, conditions, and limitations, is a prerequisite for its classification as a smart contract, constituting an operational requirement for its efficacy and execution[5]. It is a contractual modality of an entirely electronic nature, for the agreement reached by the parties is recorded electronically and its stipulated

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[1] Szabo, Nick. 1994. "Smart Contracts."Accessed January 21, 2026. https://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart.contracts.html.

[2] Lourenço, Henrique Soares Delgado. "Smart Contracts. Enquadramentos e Desafios." Lusíada. Direito, série 2, no. 32 (2024): 33. Accessed January 21, 2026. https://repositorio.ulusiada.pt/handle/11067/7752

[3] Rey, Jorge Feliu. "Smart Contract: Conceito, Ecossistema e Principais Questões de Direito Privado." Revista Eletrônica Direito e Sociedade - REDES 7, no. 3 (2019): 100. Accessed January 21, 2026.https://doi.org/10.18316/redes.v7i3.6120.

[4] Rey, 100

[5] Rey, 100

clauses are executed on the Blockchain network itself[6]. From the pre-negotiation phase through to the contract's performance, the entire process of formation and conclusion occurs digitally[7]. The operational logic of smart contracts necessitates their existence in digital form, this is an indispensable requirement for validating their creation and enabling their operation, precluding the possibility of using a solely written or verbal format[8].

2.2. Analysis of Blockchain Technology

The Blockchain is a distributed and decentralised data ledger technology, implemented using cryptography[9]. This technology was popularised anonymously, or more precisely pseudonymously, by an individual or group operating under the name Satoshi Nakamoto in 2008. In this implementation, Blockchain technology serves as the mechanism for recording transactions involving the cryptocurrency Bitcoin[10]. The characterisation of the Blockchain as a system defined by its "distributed" and "decentralised", reveals two essential dimensions of Blockchain technology. First, each user of the Blockchain possesses individual access to it, maintaining an updated copy of the entered information, which they download to their personal computer this constitutes its distributed nature[11]. Second, it means that no single entity controls the Blockchain, rather, its users collectively "control" the entered information[12]. This stands in direct opposition to a centralised network, which presupposes control over user transactions by a single entity[13]. Consequently, the Blockchain ultimately functions as "a digital database shared by a group of users, founded upon the Internet"[14].

The network of participants, termed a "distributed ledger", enables the recording and validation of information entered onto the platform to be performed by the users themselves without external intervention[15]. This fosters and facilitates a relationship of trust in digital space,

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6 Bastos, Micaela Sofia Reis. "(In)validade dos smart contracts." Master's thesis, Universidade Católica Portuguesa, 2022, 12. Accessed January 21, 2026. https://repositorio.ucp.pt/handle/10400.14/40628.
7 Bastos, 12
8 Bastos, 12
9 Machado, José Manuel Pinho Leite Rodrigues. "A blockchain e o direito: os smart contracts em especial." Master's thesis, Universidade Católica Portuguesa, 2022, 8. Accessed January 21, 2026. https://repositorio.ucp.pt/handle/10400.14/39897.
10 Machado, 8
11 Machado, 9
12 Machado, 9
13 Machado, 9
14 Machado, 9
15 Machado, 9

eliminating the need for an intermediary to guarantee that relationship[16]. This constant, decentralised oversight, carried out by the platform's users, confers unparalleled security and immutability upon the recorded information, unlocking possibilities both within and beyond the sphere of Law that were hitherto impossible[17]. In more succinct terms, a blockchain constitutes a distributed ledger technology for recording data, information, and digital assets[18]. This record is maintained in a distributed, synchronised, and decentralised manner across all storage and validation points within an internet-based network, known as nodes, which are essentially peer computers[19]. It enables the maintenance, validation, and transaction of this recorded data, information, and assets across the dispersed nodes without intermediaries, through consensus mechanisms between the data storage and validation points[20]. By utilising the platform's numerous nodes for storage, validation, and security, the information concerning data and transactions entered into the blockchain network is not centralised within a single entity but is instead distributed across these network nodes[21]. Consequently, users of this technology do not depend on a centralising authority to access this information. Each node maintains a copy of all transactions and records previously included on the blockchain, grouped into 'blocks' that are linked to all prior, cryptographically validated 'blocks'[22].

A blockchain is, therefore, a type of decentralised ledger technology. This allows anyone to verify data included on the blockchain while preventing its unilateral modification, as each information 'block' is chained to the others[23]. Any alteration or modification of data entered into the network first requires achieving consensus from a vast number of computers (nodes), before the alteration to the recorded information can be propagated[24]. As a rule, the records created are immutable[25]. As previously noted, the popularisation of Blockchain technology occurred from 2008 onward, rendering it a relatively recent innovation in terms of legal regulation[26]. Although

[16] Machado, 9
[17] Machado, 9
[18] Kalache, Eduardo Menescal. "Sobre a rigidez dos smart contracts e a alteração das circunstâncias." Master's thesis, Universidade de Lisboa, 2024, 20. Accessed January 21, 2026. https://repositorio.ulisboa.pt/entities/publication/afbd157c-2c35-4109-8b6b-c48ea2a41126.
[19] Kalache, 20
[20] Kalache, 20
[21] Kalache, 20
[22] Kalache, 20
[23] Kalache, 20
[24] Kalache, 21
[25] Kalache, 21
[26] Machado, 12

several years have since elapsed, the fundamental nature and technological novelty of Blockchain continue to present significant challenges for its definitive characterization, legal classification, and governance[27]. The pace of technological innovation complicates the task of keeping legal frameworks apace, as it continuously gives rise to novel, valid legal questions that are inherently difficult to resolve[28]. One such question concerns the precise legal qualification of the Blockchain itself[29]. Analytically, the Blockchain functions as a community-based system, with multiple users interacting simultaneously and on an equal level, it is therefore necessary to clarify the legal nature of this relationship[30]. Given the diversity of participants, who may have no prior connection to one another, may possess divergent objectives, and may interact with the system in fundamentally different ways depending on their user type the sole common thread is the Blockchain itself[31]. The collective objective is the platform's proper functioning, irrespective of the individual aims each user may pursue through or beyond it[32].

3. Operational Benefits of Blockchain and Smart Contracts in the Oil Industry

This section examines the transformative impact of smart contracts and blockchain technology on the oil industry (3.1.), highlighting their roles in enhancing transparency, operational efficiency (3.2.), and strengthening regulatory compliance (3.3.).

3.1. The Role of Smart Contracts and Blockchain in Modern Oil Trading

As a result of the digitalisation and automation of industrial processes, smart contracts are computer programmes that execute automatically upon the fulfilment of predetermined conditions, eliminating the need for intermediaries and significantly reducing the scope for errors and disputes[33]. The application of this blockchain technology in the petroleum sector offers a novel approach to the process of agreement management, impacting stages ranging from the purchase and sale of crude oil and refined products to the administration of logistical and supply

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27 Machado, 12
28 Machado, 13
29 Machado, 13
30 Machado, 13
31 Machado, 13
32 Machado, 13
33 "Impacto de la Tecnología Blockchain en el Sector Petrolero," Inspenet, November 4, 2025, Accessed January 21, 2026. https://inspenet.com/articulo/impacto-blockchain-en-el-sector-petrolero/.

operations[34]. Smart contracts can encode various contractual terms to execute an agreement, price, volume, and delivery conditions are among the principal parameters considered during their design and preparation[35]. Once the agreed parameters are verified via trusted data feeds such as IoT sensors, the smart contract is triggered automatically, facilitating invoicing and financial settlements without any manual intervention[36]. The implementation of smart contracts enhances operational efficiency by removing manual steps and accelerating access to commercial data, all while improving transactional security through the immutability and transparency inherent to blockchain technology[37]. Smart contracts stand as one of the most significant blockchain applications in the petroleum industry, representing a landmark in the sector's digitalisation and automation[38].

3.2. Transparency and Operational Efficiency

One of the advantages of using blockchain in petroleum technical transactions lies in the enhanced transparency and traceability it offers[39]. In traditional supply chains, tracing the origin, movement, and quality of oil and gas products, as well as associated technical services, can be extremely challenging[40]. Blockchain, characterised as a decentralised and immutable ledger, records all transactions in a sequential and transparent manner[41]. Blockchain technology ultimately simplifies the petroleum technical transaction process, generating significant efficiency gains and cost savings[42]. In traditional transactions, there are typically multiple intermediaries involved, such as banks, brokers, and regulatory agencies[43]. These intermediaries add complexity, time, and cost to the process. With blockchain, smart contracts can be used to automate many of the processes involved in technical transactions[44].

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[34] Ibid.
[35] Ibid.
[36] Ibid.
[37] Ibid.
[38] Ibid.
[39] Dalian Yisen Energy System Co.,Ltd. Blog. Accessed January 21, 2026. https://pt.oil-gassuperchargedsystem.com/blog/how-does-blockchain-technology-impact-oil-and-gas-technical-transactions-6074.html
[40] Ibid.
[41] Ibid.
[42] Ibid.
[43] Ibid.
[44] Ibid.

A smart contract is a self-executing contract with its terms directly written into code. For example, when a company signs a technical services contract, the smart contract can automatically release payment once the service is completed and verified on the blockchain[45]. This eliminates the need for manual invoicing, payment processing, and reconciliation, reducing administrative costs and processing time. In the oil industry, different parties often maintain their own records of transactions, which can lead to discrepancies and inefficiencies[46]. By using a shared blockchain ledger, all parties have access to the same set of data, eliminating the need for duplicate record-keeping and reducing the potential for errors[47].

3.3. Regulatory Compliance

The oil industry is heavily regulated, and compliance with various regulations presents a significant challenge. Blockchain can streamline the regulatory compliance process by providing a transparent and auditable record of all transactions[48]. Regulatory bodies can access the blockchain to monitor and verify compliance with environmental, safety, and financial regulations[49]. For example, when our company provides technical services, the blockchain records all environmental impact data, such as emissions and waste management[50]. This data can be easily accessed by regulatory authorities, ensuring our compliance with environmental regulations[51]. Furthermore, blockchain can help reduce the administrative burden associated with regulatory reporting. Instead of submitting multiple reports and documents, companies can provide regulators with access to the relevant blockchain data as needed[52].

4. Obstacles to the Implementation of Smart Contracts in the Oil Industry

In this section, the main legal and practical obstacles associated with the adoption of smart contracts in the oil industry will be analyzed, highlighting their inflexible and immutable nature (4.1.), the difficulties arising from unforeseen circumstances (4.2.), the controversies regarding

[45] Ibid.
[46] Ibid.
[47] Ibid.
[48] Ibid.
[49] Ibid.
[50] Ibid.
[51] Ibid.
[52] Ibid.

their interpretation (4.3.) , and the particular features of contracts in this industry, which are characterized by a high degree of complexity, long duration, and substantial financial risks (4.4.).

4.1. The Conflict Between Smart Contract Immutability and Legal Flexibility

The inherently rigid and immutable nature of smart contracts stands in direct opposition to the flexible and adaptable legal regime characteristic of conventional civil contract regulation[53]. This tension is particularly evident at the level of performance[54]. While the automatic execution of smart contracts is touted for enhancing security by reducing typical uncertainties such as non-performance, it directly contrasts with the legal institutions like the issue of unforeseen circumstances provided for by traditional contract law to manage contractual uncertainty[55]. The integration of smart contracts into a decentralised and distributed ledger technology, which prevents the alteration of stored information and renders the contract immutable, fundamentally clashes with the inherent flexibility of traditional contracts[56]. This presents a complex problem regarding how these two contractual paradigms considering the former as a contract can coexist within the same legal regime[57].

4.2. The Issue of Unforeseen Circumstances

A smart contract can be replaced for future agreements of will, but it cannot be edited or have its effects reversed[58]. Consequently, although smart contracts deliver considerable benefits and operational efficiencies, their immutability precludes the accommodation of subsequent dissatisfaction, the occurrence of unforeseen circumstances, or any ex-post-facto interpretive adjustment[59]. This contracting modality is thus seen as enshrining the principle of *pacta sunt servanda* in its most absolute and integral form. A comparison with classical contracting reveals a fundamental divergence[60]. Despite potentially higher transactional costs, traditional contracts

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[53] Lourenço, Henrique Soares Delgado. “Smart contracts: enquadramentos e desafios.” Lusíada. Direito 32 (2024): 44. Accessed January 21, 2026. https://doi.org/10.34628/07Y6-EQ80.
[54] Lourenço, 44
[55] Lourenço, 44
[56] Lourenço, 44
[57] Lourenço, 44
[58] Rech, Matheus Bortoluz
“Smart contracts: formação e aplicabilidade no Direito português” (master’s thesis, Universidade de Lisboa, 2024): 101.Accessed January 21, 2026. https://repositorio.ulisboa.pt/handle/10400.5/96398.
[59] Rech, 101
[60] Rech, 101

allow for the renegotiation of clauses or the termination of performance. The parties retain the recourse to judicial proceedings to rectify apparent contractual defects or to have any disruption caused by unforeseen circumstances recognised and adjudicated[61]. In contrast, smart contracts render such solutions profoundly difficult, as reversing a transaction recorded on a Blockchain network would be a modification to the platform's validation protocol, requiring the creation of a new operational rule that invalidates the previous one[62]. Regarding the supervening excessive hardship of an obligation due to unforeseen circumstances in a contract, these are cases where the obligation and its performance become extremely prejudicial to one party because of this incidental event[63]. This does not necessarily constitute an absolute impossibility of performance, but rather a situation where this change exceeds the risk originally assumed under the contract[64]. In other words, performing the obligation after the occurrence of this new circumstance would impose a hardship so substantial that enforcement would run counter to the principle of good faith[65]. This supervening excessive hardship is also referred to as relative impossibility. It is not confined solely to the financial impossibility of performance, but also encompasses the excessive risk one party assumes in light of the other's interests, thereby warranting protection for the aggrieved party[66]. As established, a smart contract operates according to its pre-programmed commands, executing strictly within its coded parameters. The programs in which it resides, given their strictly digital nature, possess no capacity for broader contextual understanding or normative discernment[67].

Thus, trust is necessarily vested in the contractual code itself, which, as a self-executing mechanism, inherently lacks any provision for contingent events such as *force majeure*[68]. In petroleum contracts, the unforeseen circumstances ultimately precludes the full implementation of smart contracts. This stems from an inherent tension: legal governance in this domain is predominantly qualitative, value-laden, and politically nuanced, in direct contrast to the objective, quantifiable, and pre-defined conditions required for algorithmic execution. This dichotomy is exemplified by hardship clauses, which invoke necessarily indeterminate standards

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61 Rech, 101
62 Rech, 102
63 Rech, 102
64 Rech, 102
65 Rech, 102
66 Rech, 102
67 Rech, 102
68 Rech, 102

including reasonable unforeseeability, excessive onerousness, economic equilibrium, and public interest. The application of such standards is not a mechanistic process but one that demands human interpretation and equitable discretion. The structure of upstream petroleum contracts exacerbates this tension. Characterized by protracted investment cycles, significant sunk costs, and acute sensitivity to exogenous variables, such as volatile commodity prices, host-state political stability, and dynamic regulatory environments, these agreements are intrinsically vulnerable to disruption. Within this context, the occurrence of unforeseen circumstances can render even marginal exogenous shifts sufficient to transmute an initially viable project into an economically unsustainable venture for one party, most notably the private investor.

4.3. Challenges of Interpretation, Adaptation, and Enforcement

The interpretation of Smart Contracts diverges fundamentally from that of traditional agreements[69]. In conventional contracts, interpretation is performed by the human mind, whereas in Smart Contracts, it is executed by a machine[70]. Consequently, the operative language of each must necessarily differ[71]. Within smart contracts, the language is necessarily more objective and precise, as the machine is incapable of detecting subjective criteria[72]. In contrast, traditional contracts employ natural human language, interpreted by the parties themselves based on more subjective standards and susceptible to individual appreciation, which inherently entails a greater degree of ambiguity[73]. When a contract is construed by a programme, it follows logically that such interpretation is confined strictly to its deterministic parameters, it cannot infer meaning beyond what is expressly transmitted[74]. In traditional petroleum contracts, interpretation must account for context, party intent, and unforeseen factors, a necessity given the complexity and variability of petroleum operations

Smart contracts, conversely, are programmed with rigid code and execute only predefined clauses based on objective data inputs; they cannot capture subjective nuances or adapt to unanticipated changes without manual intervention. This fundamental divergence in interpretive methodology creates a structural impediment to the use of smart contracts in petroleum

[69] Bastos, Micaela Sofia Reis, "(In)validade dos smart contracts" (master's thesis, Universidade Católica Portuguesa, 2022), 23.Accessed January 21, 2026. https://ciencia.ucp.pt/en/studentTheses/invalidade-dos-smart-contracts.

[70] Bastos, 23

[71] Bastos, 23

[72] Bastos, 23

[73] Bastos, 23

[74] Bastos, 23

agreements. The contractual framework within the petroleum sector inherently demands adaptive clauses and negotiations grounded in subjective criteria (such as force majeure, economic conditions, or technical performance) which are exceedingly difficult to codify within automated programming languages. In upstream contracts, clauses such as good international petroleum industry practice, economic equilibrium, renegotiation, or stabilization play an essential role in maintaining contractual balance within long-term agreements characterized by high risk and regulatory variability. These clauses aim to ensure the continuity of the contractual relationship, mitigating the risk of frustration of the legal transaction in the face of unpredictable events. The multi-year duration of various contractual clauses, combined with dependence on sovereign acts (fiscal, environmental, local content), renders a rigid, closed contractual model unsuitable

This explains the centrality of adaptation, stabilization, and periodic review clauses. Their implementation requires case-by-case assessment, teleological interpretation, and equitable balancing of all intellectual operations that elude the binary logic of smart contract code. Computer code operates through conditional instructions (if-then), generating automatic behaviors within a logical chain. While efficient in terms of execution, this structure is incapable of processing legal values or customary practices that depend on variable circumstances. A codified clause cannot, by itself, interpret the spirit of the contract, assess the reasonableness of conduct, or adapt to unpredictable changes in petroleum legislation or market conditions. Human interpretation thus remains necessary to adjust or resolve complex contractual disputes, whereas smart contracts possess no autonomous interpretive capacity. This deficiency creates material risk if the coded conditions fail to account comprehensively for real-world situations. The rigidity and inherent interpretative limitation of smart contracts thus constitute a structural impediment to their broad application in petroleum agreements, where human flexibility and interpretive judgment are essential to ensuring both contractual fairness and the continued viability of the parties obligations.

4.4. The Structural Complexity and Temporal Scope of Petroleum Contracting

A defining feature of petroleum contracts is their inherent complexity and extended duration, involving multiple parties including sovereign states, state-owned enterprises, transnational corporations, and private investors[75]. The growing demand for the enforcement of contractual obligations within the energy sector (against a backdrop of currency fluctuations, regulatory shocks, and political tensions) highlights the inadequacy of traditional state-based jurisdictional mechanisms[76]. Illustratively, the forfeiture clause, commonly incorporated into joint operating agreements linked to petroleum exploration and production concessions, constitutes a legitimate mechanism for the proactive management of contractual risk[77]. This clause authorises the exclusion of a non-performing party, specifically one that fails to meet its capital contribution obligations (cash calls), from the consortium without entitlement to reimbursement or compensation for funds previously invested[78]. This mechanism seeks to ensure the continuity of the concession and the contractual equilibrium by permitting the removal of the non-performing party, thereby preventing its default from jeopardising the project's execution[79]. It also releases the remaining parties from future obligations towards the excluded member[80]. Its validity, however, is contingent upon its exercise being grounded in objective good faith and within the limits of the contract's social function, thereby preventing abuses and safeguarding the stability of the consortium's business plan[81].

The exploration and production sector has for decades been one of the most capital, technology, and risk-intensive industries, requiring robust contractual and institutional frameworks to attract long-term investment[82]. Operations in the upstream phase involve high sunk-cost decisions, significant geological uncertainty, geopolitical volatility, and extended financial return cycles[83]. Consequently, contractual modelling reflects, to a certain degree, the state's level of control over resources, investor risk appetite, the country's regulatory maturity, and the global competitive environment for exploratory capital[84]. Thus, these contracts are not merely instruments for

[75] Maia, Alberto Jonathas. "A arbitragem no setor de petróleo e gás natural: complexidade contratual e racionalidade econômica." Revista dos Tribunais 1079 (setembro de 2025), 3.Accessed January 21, 2026. https://dspace.almg.gov.br/handle/11037/64958.
[76] Maia, 3
[77] Maia, 3
[78] Maia, 3
[79] Maia, 4
[80] Maia, 4
[81] Maia, 4
[82] Maia, 4
[83] Maia, 4
[84] Maia, 4

resource extraction; they are also tools of energy policy and industrial development, shaping investment flows, revenue sharing, and resource sovereignty[85].

In the context of upstream operations (the initial phase of the oil and natural gas production chain encompassing exploration, appraisal, development, and production activities) four primary contractual models stand out:

(i) the concession or licence contract; (ii) participation agreements; (iii) the production sharing agreement; and (iv) the risk-service agreement[86].

Each of these models embodies distinct legal frameworks for allocating risks, apportioning revenues, and defining title to the extracted resources[87]. The concession contract is a model whereby the host state temporarily transfers to a private company or consortium the right to explore for, develop, and produce oil and natural gas within a designated area, in exchange for the payment of taxes, royalties, and special participations[88]. The concessionaire assumes all operational risks and costs but retains autonomy to market the extracted production, acquiring ownership of the petroleum upon its extraction[89].

Participation agreements, in turn, do not constitute a standalone contractual model but are instruments that define the terms of state participation in joint ventures or joint operating agreements (JOAs) formed between foreign companies and national oil companies[90]. These agreements establish how the state (or its designated national oil company) partners with the private operator, potentially sharing investments, risks, and revenues. This model closely resembles the structure of joint operating agreements, which are widely used in the sector[91]. The risk-service agreement (RSA) is a model under which a foreign company conducts exploration and production at its own cost and risk but holds no title to the extracted production[92]. The state retains full ownership of the petroleum and remunerates the company through fixed or variable payments, typically tied to production volumes or operational costs[93]. This model is common in

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93 Maia, 5

countries seeking to preserve sovereignty over natural resources while requiring technical expertise and private investment[94]. For the contracted company, however, the risks are significant: in the absence of a commercial discovery, all costs become unrecoverable[95]. Conversely, in the event of success, compensation is calculated according to pre-agreed criteria based on operational efficiency and rate of return[96]. Numerous material metrics within risk-service agreements are either qualitative in nature or contingent upon expert assessment such as "good petroleum engineering practices," acceptable levels of non-attributable downtime, or prudential criteria for third-party contracting[97]. This inherent qualitative dependency renders them resistant to translation into deterministic, binary code. Upstream contracts are, in many instances, extensions of public energy and industrial development policies, not merely private market agreements. The state employs clauses mandating investment obligations, production participation and sharing, environmental and social targets, and statutory duties (such as upholding federal ownership of subsurface natural resources, ensuring environmental and social protection, operational safety, waste management, among others) as instruments of policy. These inherently depend on administrative supervision, regulatory interpretation, and discretionary decision-making.

The rigid automation characteristic of smart contracts is incompatible with the state's need to adjust requirements and interpret obligations in light of the public interest and the evolution of the energy sector. Furthermore, the multiplicity of normative sources (hydrocarbons law, environmental, fiscal, competition, safety, and labour regulations) makes it difficult to encapsulate the entire legal regime within stable, programmable rules. This is because a significant portion of the relationship is mediated by regulatory bodies, courts, and arbitral tribunals, not by automated programmes. The complex nature of upstream contracts requires interpretation in accordance with Administrative and Regulatory Law, not solely private autonomy. The so-called "regulatory function of the contract" is central here: the contract serves as a legal instrument for executing energy policies, whose economic-legal equilibrium extends beyond the mere exchange of performances to encompass the fulfilment of public objectives,

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[94] Maia, 5
[95] Maia, 5
[96] Maia, 5
[97] McNair, Damian. "EPC Contracts in the oil and gas sector." In Investing in Infrastructure: International Best Legal Practice in Project and Construction Agreements. PwC Australia, January 2016.Accessed January 21, 2026. https://www.pwc.com.au/legal/assets/investing-in-infrastructure/iif-5-epc-contracts-oil-gas-feb16-3.pdf

supply security, national technological development, environmental sustainability, and sovereign appropriation of petroleum revenues. With the advent of smart contracts and the digitalisation of upstream operations, a new legal frontier emerges. The automation of contractual obligations and the integration of sensors and blockchain into measurement and production allocation systems tend to reduce informational asymmetry between the state and operators. However, this raises questions of regulatory governance: to what extent can the state delegate the automation of supervisory and control clauses without compromising its prerogative as a public authority? Encoding environmental or investment obligations into self-executing algorithms necessitates hybrid mechanisms of legal-technological interoperability, where principles of proportionality, transparency, and public audit must be digitally incorporated. Ultimately, the application of smart contracts to upstream petroleum contractual models is inherently problematic. These contracts deal with high risks, significant uncertainty, substantial state intervention, and highly open-textured, flexible clauses, whereas smart contracts demand objective, pre-determined rules that are largely resistant to subsequent interpretation or alteration.

5. Conclusion

The analysis developed throughout this study demonstrates that, while significant benefits exist in utilizing smart contracts within the petroleum industry, representing an inflection point in how upstream and midstream energy operations are conceived and executed, their practical application remains constrained. When structured under a robust legal governance framework and linked to blockchain-based audit mechanisms, these instruments enable the automation of contractual obligations while ensuring traceability and transparency across the value chain. The capacity for regulatory bodies to access the network in real time to monitor environmental, safety, and financial compliance reinforces the role of smart contracts as instruments of regulatory effectiveness. The integration of technology and regulation generates material gains in economic efficiency, transaction cost reduction, and legal risk mitigation, particularly in fulfilling quality standards and distributing payments and royalties. This limitation stems largely from the intrinsic complexity of petroleum contracts, instruments involving multiple parties, state interests, long-term clauses, and contingent provisions that are difficult to translate into algorithmic language. The deterministic, automatic, and rigidly pre-programmed nature of smart contracts, anchored in a binary “if–then” logic, contrasts with the necessary flexibility, interpretive openness, and scope for negotiation that characterize contractual obligations in this domain. In petroleum contracting, dynamic adaptation to supervening circumstances and the role of judicial or arbitral mediation remain indispensable. Consequently, the position that emerges from this study is that genuine legal-contractual innovation lies not in replacing the classical petroleum contract with a smart contract, but in their functional integration. This constitutes a form of contractual hybridisation, whereby the smart contract operates as an executive layer for the automatic performance of standardised, measurable obligations. The traditional petroleum contract, in its conventional form, preserves its role as the overarching normative framework. It remains the essential instrument for allocating risk in contexts of uncertainty, for providing juridical and value-based interpretation, and for re-establishing contractual equilibrium in the face of unforeseen circumstances.

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