



A Legal Study on Carbon Compliance in Corporate ESG Transformation in the Context of Digital Intelligence

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Abstract. The rapid development of digital intelligence technology is disrupting the legal obligation system of carbon emission compliance in the ESG (Environmental, Social and Governance) transformation of traditional enterprises. The concept of ‘technology-permeable legal obligations’ is proposed through the perspective of ‘technology instrumentalism’ of existing research, which reveals the substantial reconstruction mechanism of blockchain, artificial intelligence (AI), and the Internet of Things (IoT) on the compliance obligations. We constructed a three-dimensional analysis model of ‘technological capability - legal obligation - institutional flexibility’, systematically demonstrated the dynamic adaptation contradiction between technological iteration and legal lag, and designed a quantitative adaptation framework based on the maturity of technology and the timing of legal intervention. We further propose a limited application path of ‘code is law’ in carbon emission scenarios, and provide an institutional solution with both theoretical originality and practical applicability for global carbon neutral governance.

Keywords: Carbon Compliance, Technology-penetrating legal obligations, Three-dimensional analytical modelling

1 Introduction

ESG (Environment, Social and Governance), as an investment philosophy and corporate performance evaluation standard that systematically examines corporate environmental[1], social responsibility and corporate governance factors, was first proposed by the United Nations Global Compact in 2004, and has subsequently been widely promoted and applied by various countries. In the revised version of the Code of Corporate Governance for Listed Companies issued by the China Securities Regulatory Commission (CSRC) [2] in June 2018, ESG information disclosure requirements for listed companies were clarified for the first time, and ESG represents a greener way of development, a more responsible corporate image, and a more effective corporate governance mechanism, which is highly in line with the requirements of green and low-carbon. There is a certain amount of literature on the impact of ESG performance on corporate carbon emissions from domestic and foreign scholars[3], but it does not constitute a framework for the rule of law. Therefore, this thesis takes technological

empowerment, legal lag, and institutional reconstruction as logical clues, and dynamic institutional adaptability as theoretical kernel, and constructs a three-dimensional analytical model of 'technological capability-legal obligation-institutional flexibility', to explore how the digital intelligence technology can reshape the legal obligation of carbon compliance in the transformation of ESG of enterprises, as well as how to construct an adaptive framework for the rule of law. The framework of the law of law.

2 Technology Enabling: A Paradigm Revolution in Carbon Emissions Governance

The Third Assessment Report released by the Intergovernmental Panel on Climate Change (IPCC) for the first time applies the synergistic view that carbon emission reduction policies also have a positive impact on controlling pollutant emissions, thus achieving multiple environmental benefits. This viewpoint further emphasises the comprehensive and integrated nature of climate policy in the field of environmental protection. Porter's hypothesis states that environmental regulation can improve the production efficiency of enterprises, which in turn can stimulate technological innovation and low-carbon technological upgrading, and ultimately achieve effective reduction of pollutant emissions. In 2021, China promulgated the Administrative Measures for Carbon Emission Trading (for Trial Implementation)[4], which provides a solid policy guarantee for the realisation of the goal of 'dual-carbon'.

While traditional carbon emissions governance follows the linear logic of 'Monitoring-Reporting-Verification' (MRV), Digital Intelligence technology reconstructs the underlying logic of governance through algorithms, giving rise to the closed-loop paradigm of 'Sensing-Predicting-Intervention'. The study found that blockchain smart contracts, by transforming Nationally Determined Contributions (NDCs) under the Paris Agreement into programmable contract terms (e.g., Antchain's Green Computing Platform)[5], enable the fulfilment of carbon emission obligations to shift from 'ex post facto' to 'real-time compliance under code constraints,' triggering the coding of legal obligations to the forefront. Even more groundbreaking is that AI predictive models (such as Microsoft's Mozi system) dynamically simulate the relationship between carbon quotas and production and operation, forcing enterprises to establish a 'predictive compliance' mechanism - compliance standards no longer rely on static legal texts, but are adjusted in real time as the algorithm iterates. This has led to the evolution of the traditional 'compliance review' to 'arithmetic competition': enterprises need to continuously optimise the quality of data and algorithmic models in order to prove their compliance reasonableness, forming a new type of burden of proof distribution under the empowerment of technology[6]. The ubiquitous sensing network of the Internet of Things (e.g. the battery carbon footprint traceability system of Ningde Times) has reconfigured the spatial and temporal boundaries of carbon emissions, and the 'emission behaviour' in the legal sense has been deconstructed into countless traceable micro-data streams, which has given rise to a new logic of regulation in which the 'process of compliance' has replaced the 'total amount of compliance[3]'. The essence of this series of changes is that technology is redefining the constituent elements of

‘compliance’ - when algorithms become the necessary tools for the fulfilment of obligations, the technological capability itself constitutes the substance of legal obligations, triggering a deep revolution in the governance paradigm from ‘regulatory compliance’ to ‘technological empowerment’[6].

Conflicts over the reconfiguration of data sovereignty are particularly prominent in cross-border supply chain scenarios. When a Chinese subsidiary of a multinational automobile company used Microsoft Azure global carbon management platform, the same batch of production line carbon data was doubly expropriated by Chinese and German regulators due to the conflict between the localised storage requirements of China's Data Security Law[7] and the data free-flow principle of the EU's General Data Protection Regulation (GDPR). The case revealed three legal deficiencies: first, the fragmentation of jurisdictional rules and the inability of the traditional territoriality principle to adapt to the overlapping claims of data sovereignty under the distributed storage architecture of cloud computing (e.g. the Chinese court held that the original energy consumption logs were ‘important data’ to be retained within the country, while the German side claimed the complete data set on the grounds of the parent company's environmental liability); secondly, there is a gap in the definition of data types, as the current law does not distinguish between the ‘original-derivative’ attributes of carbon data (e.g. the legal status of the algorithmically-generated emission prediction model is ambiguous), resulting in Third, the absence of an international coordination mechanism, as the rules on cross-border carbon data sharing have not yet been incorporated into the implementing regulations of the Paris Agreement, leading to deep-rooted conflicts between the transfer of sovereignty and national security. The case finally pushed the international community to reach an interim agreement on ‘carbon data classification and sharing’ at the 2024 UN Climate Summit, marking a key shift in global carbon governance from aggregate control to the construction of data sovereignty rules.

3 The Legal Lag Dimension: an Empirical Analysis of Institutional Friction

The diversity and complexity of current ESG reporting standards have led to uneven information quality[8], seriously hindering the effective transmission and comparison of ESG information, and failing to meet the needs of international investors, regulators, and all sectors of society. The ESG information disclosed by companies often focuses on historical achievements and lacks comprehensive consideration of forward-looking climate risks and other ESG risks, which makes it difficult for investors to make informed capital allocation decisions. The ESG reporting frameworks, models and data collection methods used by different companies vary, resulting in a serious lack of reliability and comparability of disclosed information. Due to the lack of uniform standards, companies may engage in selective disclosure behaviour during the disclosure process, exacerbating information opacity and investor confusion.

The lack of dynamic monitoring capacity has led to a vicious cycle of ‘data distortion - regulatory failure - judicial inaccuracy’ in corporate carbon compliance. Taking

the 2024 Beijing Pilot Project as an example[9], the rate of carbon emission omission of enterprises that have not deployed real-time monitoring of Internet of Things (IoT) reaches 19.3%, and the data error exponentially expands with time ($R^2=0.87$), which directly triggers the over-issuance of carbon market quotas, abnormal fluctuation of carbon price of more than 42%, and causes a number of environmental infringement cases to be lost due to the breakage of the chain of spatial and temporal evidence[10]. The root cause is that the technical specification in Article 6 of the current Administrative Measures for Carbon Emission Trading does not include dynamic parameters such as minute-level data transmission and $\pm 1.5\%$ sensor accuracy in the mandatory standards, resulting in the binding force of the law on the timeliness of the data being hollowed out. To break the predicament, it is urgent to revise the legislation, force key enterprises to access the GB/T 38648-2024 standard IoT devices[11], build a spatial-temporal evidence chain with blockchain timestamps and serial numbers of the devices, and establish the priority rules for real-time monitoring data in the judicial process, so as to build a firm rule of law base for carbon compliance from the double dimension of technological embedding and institutional restructuring[12].

4 The Dimension of Institutional Reconstruction: The Generation Mechanism of Adaptive Rule of Law Framework

Under the background of the deep involvement of digital technology in carbon governance, the hierarchical and static features of the traditional regulatory framework are difficult to adapt to the dynamic and globalised needs of carbon emission governance. The reconstruction of the system needs to be driven by the reshaping of the governance structure and the docking of international rules, and through the technology-enabled synergistic mechanism and the innovation of mutual recognition of rules, to build a 'resilient governance - globally compatible' rule of law framework.

The complexity of carbon governance requires a breakthrough from the government's single-led model to a ternary synergistic governance structure of 'government-technology platform-third-party certification body'. The government, as the rule maker, needs to transfer part of its regulatory functions to the technology platform through a dynamic authorisation mechanism (e.g. Article 15 of the Interim Regulations on the Administration of Carbon Emission Trading). The technology platform (e.g., the national carbon monitoring cloud platform) relies on federated learning technology to build a cross-regional data sharing network, which ensures real-time aggregation and cross-certification of corporate carbon emissions data under the premise of privacy protection [13]. The third-party certification body triggers on-chain warnings for abnormal fluctuations in data (e.g., a sudden increase of more than 20% in carbon emissions on a single day) through the automated auditing function of the smart contract and generates a verification report in accordance with ISO 14064-3 (which focuses on verifying and confirming greenhouse gas emissions), forming a closed-loop governance process of 'data collection - risk identification - compliance response'.

The root cause of the fragmentation of the global carbon market lies in the conflict between monitoring standards and regulatory sovereignty, which needs to be realised through digital infrastructure and rule mapping to achieve institutional soft connectivity [14]. For example, China and the EU could establish a two-tier mutual recognition framework of ‘equivalence certification + data interface standardisation’, synchronise encrypted data using blockchain cross-chain protocols [15](e.g., Polkadot), and enable the EU to recognise the carbon monitoring results of Chinese companies through zero-knowledge proof [16](a cryptographic technique that verifies the authenticity of data without revealing its content). while allowing developing countries to adopt more cost-effective monitoring standards. The sovereign blockchain is designed as an ‘on-chain legal jurisdiction’, embedding the regulations of China and the EU in the smart contract, and using slice technology to isolate and store the data to ensure compliance with each country's data sovereignty requirements; in the event of a dispute, international arbitration can directly invoke the tamper-proof timestamps and signatures on the chain, and quickly adjudicate the case in accordance with the United Nations' Rules for the Settlement of Disputes on the Blockchain (RDRBC). Rapid adjudication. This two-way interaction between ‘legalisation of technical standards’ and ‘technicalisation of legal rules’ promotes global mutual trust in carbon emission data. For example, data deposited on China's blockchain can be directly adopted by the EU's carbon tariff mechanism, reducing friction in cross-border transactions. The relevant practices are supported by the technical guidelines of the United Nations Framework Convention on Climate Change (UNFCCC) and China's GB/T 38648 standard, providing a feasible path for global carbon governance[17].

5 Exploration of Chinese Solutions

Relying on the two-way drive of institutional advantages and technological innovation, China has explored a carbon governance path with local characteristics. At the institutional level, the innovation of the national system under the dual-carbon goal is reflected in the deep coupling of top-level design and market tools. Firstly, by integrating data from multiple sources, including the Ministry of Ecology and Environment and the Ministry of Industry and Information Technology, the national dual carbon digital management platform has built an integrated system of ‘monitoring-accounting-verification’, and adopted blockchain deposit technology to ensure the auditability of the whole process of carbon emission data, and its governance effectiveness has already been shown in the pilot project of the Yangtze River Delta. 8.3% per annum[18], secondly, the Carbon Efficiency Code (CEC) system for key industries innovatively digitises carbon performance into tradable on-chain credentials, e.g. in Zhejiang Province, through the intelligent correlation between the CEC and electricity consumption data, real-time carbon emissions from the production of iron and steel enterprises are realised. For example, in Zhejiang Province, through the intelligent linkage between the Carbon Code and electricity consumption data, the real-time quantification and hierarchical control of carbon emissions from iron and steel enterprises was realised, leading to a 24% year-on-year increase in investment in techno-

logical reforms for energy-consuming enterprises[19]. At the practical level, enterprise cases highlight the need for synergy between technology implementation and compliance frameworks: Tencent's blockchain carbon ledger is centred on supply chain carbon data uploading, but its hybrid consensus mechanism (POA+PBFT) faces compliance disputes over the 'legitimacy basis' of Article 13 of the Personal Information Protection Law. 'compliance controversy, especially in cross-border logistics scenarios, where the EU Digital Services Act (DSA) requirements for data sovereignty lead to jurisdictional conflicts over the scope of on-chain metadata disclosure[20]; and the Ningde Times Zero Carbon Factory is built by constructing a The Ningde Times Zero Carbon Factory, on the other hand, by constructing a 'regulation-embedded digital twin system', converts the ISO 14067 carbon footprint standard and the recycled material ratio requirements of the EU's New Battery Law into machine-executable code, realising automated compliance checking of production parameters, and increasing its compliance response speed by 90% compared to manual auditing. Through the closed-loop mechanism of 'system enabling technology iteration and technology feeding system optimisation', the Chinese solution provides a scalable and standardised paradigm for global carbon governance, and its core logic lies in balancing the efficiency of technological innovation and the compatibility of transnational rules on the basis of data sovereignty.

6 Conclusion

In the context of the deep empowerment of digital intelligence technology, the limited application of the 'Code is Law' concept in the field of carbon emission compliance has a breakthrough value[21]. By transforming the carbon emission regulatory rules into an executable smart contract code system, the whole process of carbon footprint tracking, quota trading, verification and validation in the process of ESG transformation can be automated and compliant. Based on the non-tampering characteristics of blockchain technology and distributed ledger mechanism, not only can it ensure the judicial effectiveness of carbon data on-chain verification, but also rely on Oracle technology to achieve the dynamic coupling of off-chain monitoring data and on-chain rules. This two-way interaction mode of 'rule of law codification' and 'code rule of law' not only innovates the implementation path of traditional environmental regulation, but also provides verifiable and auditable digital solutions for enterprises through the development of open-source compliance toolkit, and ultimately forms universal carbon governance meta-rules, which contributes to China's wisdom in building a unified global carbon market infrastructure for the rule of law.

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