Data-Driven Financial Governance in Energy Sector Audits: A Framework for Enhancing SOX Compliance and Cost Efficiency

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Abstract- ***The energy sector, particularly in its intersection with regulatory compliance and cost-intensive operations, faces unprecedented challenges in aligning financial governance with Sarbanes-Oxley (SOX) mandates. This paper presents a data-driven audit framework tailored for energy companies to enhance SOX compliance and achieve cost efficiency. Drawing on a mixed-methods analysis incorporating financial analytics, machine learning audit tools, and regulatory policy models, the study constructs a multi-layered governance model grounded in real-time data orchestration and predictive controls. The proposed framework aims to equip energy sector CFOs, auditors, and compliance officers with actionable strategies to streamline internal controls, detect anomalies early, and drive down audit costs without compromising regulatory rigor. Empirical validation across five multinational energy firms confirms the model's effectiveness in improving audit reliability, compliance timelines, and resource allocation. The findings suggest that integrating advanced data governance principles into audit design not only improves compliance posture but also serves as a strategic lever for financial resilience.***

Index Terms- ***SOX compliance, energy audit, financial governance, data-driven framework, cost efficiency, predictive controls***

I. INTRODUCTION

The globalization of energy markets and increasing public scrutiny of corporate accountability have elevated the stakes for financial governance in energy sector audits. Energy companies, due to their scale, complexity, and exposure to geopolitical and environmental risks, operate under intense regulatory oversight. One of the most significant legislative frameworks in this context is the Sarbanes-Oxley Act (SOX), enacted in 2002 to restore public confidence in the financial integrity of public corporations [1], [2]. While SOX compliance remains mandatory for publicly traded companies, achieving it efficiently particularly in capital-intensive sectors such as oil, gas, and renewables has become increasingly difficult.

The primary challenge lies in reconciling robust internal controls with the dynamic nature of financial operations in the energy sector. Traditional audit processes manual, retrospective, and siloed are ill-suited to the fast-paced financial landscape characterized by fluctuating energy prices, decentralized operations, and intricate capital project lifecycles [3], [4]. This disconnect results in inefficiencies, higher audit costs, and an elevated risk of non-compliance.

In response to these pressures, the concept of data-driven financial governance has emerged as a transformative approach. It leverages real-time data analytics, automated workflows, and machine learning tools to monitor, assess, and enforce

financial controls with unprecedented precision [5], [6]. In the context of SOX compliance, this paradigm shift enables continuous auditing, predictive risk assessment, and granular accountability key ingredients for proactive governance.

Despite the theoretical appeal of data-driven audits, their practical implementation in the energy sector is limited by fragmented data ecosystems, legacy systems, and a lack of standardized frameworks [7], [8]. Additionally, audit teams often face challenges in translating technical data outputs into actionable compliance insights. Therefore, there is an urgent need for a structured, sector-specific framework that aligns data-driven governance with SOX requirements while enhancing cost efficiency.

This paper aims to fill this gap by proposing and validating a comprehensive framework for data-driven financial governance tailored to the energy sector. It builds on existing audit and compliance literature, incorporates industry best practices, and integrates advanced data analytics capabilities. Specifically, the study seeks to:

1. Identify the core challenges of SOX compliance in the energy sector.
2. Map the current state of audit data ecosystems across selected energy firms.
3. Develop a multi-layered governance model that integrates real-time data analytics into SOX audit workflows.
4. Evaluate the model's impact on compliance timelines, cost efficiency, and risk mitigation through empirical analysis.

II. LITERATURE REVIEW

The emergence of data-driven financial governance in the energy sector marks a critical inflection point for enhancing transparency, compliance, and cost-efficiency. Amid growing regulatory scrutiny particularly under frameworks like the Sarbanes-Oxley Act (SOX) the integration of advanced analytics and automated auditing has become indispensable. This section reviews foundational and recent academic work, industry reports, and regulatory analyses that define the intellectual landscape of financial governance, SOX compliance, and energy sector audit transformation.

2.1 The Evolution of SOX Compliance in the Energy Sector

The passage of SOX in 2002 redefined corporate financial oversight by mandating stringent internal controls and management accountability. Its implications have been particularly pronounced in capital-intensive sectors like energy, where financial misstatements can have systemic repercussions [9], [10]. Scholars have noted that the high compliance costs associated with SOX disproportionately impact firms with complex asset structures and decentralized operations, such as utilities and oil corporations [11]. As a result, many energy firms initially struggled to align legacy financial systems with the new regulatory mandates.

Several studies have investigated how energy companies adapted to SOX requirements by redesigning their governance frameworks, enhancing documentation protocols, and introducing internal control automation [12], [13]. While these efforts improved transparency, they also created operational inefficiencies due to increased administrative overhead [14], [15]. This trade-off has driven interest in data-driven governance as a means to streamline SOX compliance while preserving regulatory fidelity.

2.2 Financial Digitalization and Audit Analytics

A parallel research trajectory has examined how digital technologies especially big data, artificial intelligence (AI), and predictive analytics have reshaped financial auditing. Digitalization enables real-time data ingestion, anomaly detection, and continuous control monitoring, thereby transforming traditional audit cycles into dynamic, risk-based processes [16], [17]. In the energy sector, where operational and financial data volumes are immense, such capabilities are particularly advantageous.

The literature underscores the potential of data-driven tools to enhance both the efficacy and efficiency of internal audits [18], [19]. For example, machine learning models have been applied to historical transaction logs to detect patterns indicative of fraud or misreporting [20], [21]. Similarly, natural language processing (NLP) has been used to analyze unstructured financial disclosures, providing audit committees with richer insights into risk exposures [22].

Despite these advances, implementation challenges persist. Resistance from legacy system vendors, skill gaps among finance professionals, and cybersecurity risks have slowed the diffusion of digital audit tools [23], [24]. Furthermore, there is a lack of standardized metrics to evaluate the effectiveness of these tools in regulated industries.

2.3 Energy Sector Financial Risk Landscape

The energy sector's financial governance is complicated by its exposure to commodity price volatility, regulatory flux, and capital-intensive project cycles. This complexity has prompted researchers to call for more adaptive and predictive risk assessment models [25], [26]. Notably, risk typologies in energy audits extend beyond transactional accuracy to include environmental liabilities, tax arbitrage, and investment misallocations.

Recent studies emphasize the need for sector-specific audit frameworks that integrate both financial and operational risk dimensions. For instance, an audit trail for a capital project in a power utility must consider procurement timelines, engineering milestones, and supply chain disruptions in addition to financial records [27]. Traditional audit systems, which prioritize periodic assessments and manual sampling, are ill-equipped to handle such multifactorial risk contexts.

In this regard, scholars have proposed the integration of enterprise risk management (ERM) systems with financial analytics platforms to create a holistic governance apparatus [28], [29]. This convergence facilitates scenario modeling, stress testing, and predictive forecasting, which are crucial for compliance in fast-evolving regulatory environments.

2.4 Data-Driven Frameworks for Governance

Several conceptual and empirical contributions have advanced the idea of data-driven governance as a catalyst for regulatory compliance and cost control. These frameworks emphasize the centrality of data quality, interoperability, and decision automation in achieving compliance objectives [30]. Key enablers include blockchain for audit trails, robotic process automation (RPA) for repetitive controls, and dashboards for executive oversight.

Energy sector applications of such frameworks have been studied in relation to smart grids, decentralized asset management, and emissions trading audits [31], [32]. While the benefits are clear real-time compliance verification, fraud prevention, and process optimization real-world deployment has been hampered by institutional inertia and fragmented data ecosystems.

Furthermore, theoretical models such as the Control-Objective Framework and the Audit Process Maturity Model have been used to benchmark organizational readiness for data-driven governance [33]. These models link audit quality to data governance maturity, highlighting the importance of metadata standards, access controls, and data lineage tracking.

2.5 Gaps and Future Directions

Despite growing enthusiasm, several gaps remain in the literature. First, there is limited empirical research quantifying the cost efficiency gains from data-driven SOX compliance in the energy sector. Most existing studies focus on generic benefits without sectoral disaggregation. Second, there is a lack of validated frameworks that align data analytics with SOX Section 404 internal control evaluations [34], [35].

Additionally, research tends to underrepresent small and mid-sized energy firms, which face unique constraints in adopting sophisticated governance technologies [36]. The interoperability of audit tools across multi-jurisdictional regulatory contexts is also underexplored, particularly in cases where subsidiaries operate under varying reporting regimes [37], [38].

To address these gaps, scholars have called for multidisciplinary approaches that integrate legal analysis, systems engineering, and behavioral economics [39]. For example, the impact of cognitive biases in audit decision-making under data overload conditions is a promising but underexplored domain [40].

In conclusion, the literature reveals a strong theoretical and empirical foundation for advancing data-driven financial governance in the energy sector. However, future research must address contextual heterogeneity, implementation barriers, and

measurement challenges to fully realize the potential of these innovations in enhancing SOX compliance and operational efficiency.

III. METHODOLOGY

This study adopts a multi-method research design to develop, validate, and analyze a data-driven financial governance framework tailored to the specific challenges of SOX compliance in the energy sector. The methodology combines qualitative case study analysis, quantitative financial performance evaluation, and a simulation-based validation of the proposed framework. This section outlines the research design, data collection processes, analytical techniques, and validation mechanisms used.

3.1 Research Design

A triangulated approach was chosen to balance the strengths and limitations of qualitative and quantitative methods. The qualitative component involved detailed case studies of four energy firms with varying degrees of digital maturity and regulatory exposure. The quantitative component evaluated the financial performance and compliance outcomes of these firms using a panel dataset spanning 2010 to 2020.

The rationale for this approach lies in its ability to capture the complex interplay between regulatory compliance, digital tool adoption, and financial efficiency. Simulation modeling was used to test the scalability and adaptability of the framework under different operational conditions and risk profiles [41], [42].

3.2 Data Sources and Sampling

Primary data were collected through semi-structured interviews with 26 audit executives, financial controllers, and compliance officers from the selected firms. Interview protocols were designed to elicit insights into digital audit practices, SOX compliance mechanisms, and perceived cost-benefit tradeoffs.

Secondary data included 10 years of annual financial reports, audit committee charters, internal control assessments, and external audit findings. Regulatory filings were sourced from the U.S. Securities and Exchange Commission (SEC) EDGAR database and cross-verified with company disclosures [43], [44].

Sampling was purposive and stratified to ensure representation across upstream, midstream, and downstream segments of the energy value chain. This approach captures sector-specific governance complexities such as commodity risk management, decentralized operations, and capital project oversight [45].

3.3 Analytical Techniques

For the qualitative analysis, NVivo software was used to code and analyze interview transcripts. Thematic analysis was applied to identify recurrent governance challenges and digital audit enablers. Themes were categorized under regulatory compliance, cost control, data infrastructure, and organizational readiness [46], [47].

Quantitative data were analyzed using panel regression models to evaluate the impact of digital audit adoption on key financial indicators, including audit fees, internal control deficiencies, and SOX 404 compliance ratings. Variables were normalized for firm size, asset base, and operational scale [48], [49].

Factor analysis was conducted to reduce dimensionality and extract latent constructs representing financial governance maturity. These constructs were then tested for internal consistency using Cronbach's alpha and for external validity using confirmatory factor analysis (CFA) [50], [51].

3.4 Framework Development Process

Based on the insights from qualitative and quantitative analyses, a data-driven governance framework was developed using design science principles. The framework includes four pillars: data architecture, control automation, real-time monitoring, and compliance intelligence. Each pillar is operationalized through specific tools, such as process mining, robotic process automation (RPA), and anomaly detection algorithms [52].

Expert validation workshops were conducted with participants from audit firms, energy companies, and regulatory bodies to refine the framework components and confirm their relevance. Feedback from these workshops informed the final framework configuration and implementation roadmap [53], [54].

3.5 Simulation-Based Validation

To assess scalability, the framework was embedded into a simulation model developed using AnyLogic software. The model emulated financial transaction flows, control break events, and compliance audit cycles across three synthetic firm profiles (small, medium, and large enterprises). Variables such as data latency, system interoperability, and audit cycle time were manipulated to test framework robustness under varying operational conditions [55], [56].

Simulation outputs were benchmarked against historical data to evaluate predictive accuracy and cost-efficiency. Key performance indicators included error detection rate, compliance time lag, audit cost per transaction, and control remediation speed [57], [58].

3.6 Ethical Considerations and Limitations

The research adhered to ethical standards in data handling, respondent confidentiality, and informed consent. All interviews were anonymized, and sensitive company data were aggregated to prevent identification. Limitations include potential selection bias due to the purposive sampling strategy and the reliance on self-reported data for qualitative insights [61] .

Additionally, the generalizability of findings may be constrained by the U.S.-centric regulatory focus of SOX, although the principles of data-driven governance have broader applicability. Future studies could extend the framework to multi-jurisdictional environments with hybrid compliance regimes [61], [62].

3.7 Summary

This methodology provides a rigorous foundation for evaluating the efficacy and feasibility of a data-driven financial governance framework in the energy sector. By integrating empirical data with simulation modeling and stakeholder validation, the study ensures both theoretical robustness and practical relevance. The subsequent section presents the results of the analysis and the performance of the proposed framework.

IV. RESULTS

The implementation and testing of the data-driven financial governance framework produced compelling results across three analytical dimensions: financial performance, compliance outcomes, and operational efficiency. This section presents the empirical findings from the qualitative, quantitative, and simulation components of the study.

4.1 Financial Performance Improvements

Firms that adopted the framework exhibited measurable improvements in financial governance indicators. Audit fees, a key proxy for audit effort and scope, declined by an average of 15.2% over the implementation period. The reduction was most pronounced in firms that fully automated transaction testing and control verification processes using RPA and AI-based tools [63], [64].

Additionally, internal control deficiencies reported under SOX 404(a) dropped significantly. Firms recorded a 40% reduction in material weaknesses and a 28% decline in significant deficiencies, indicating a stronger internal control environment [65], [66]. These outcomes were corroborated by a parallel increase in audit committee satisfaction scores, derived from internal surveys and post-audit feedback mechanisms [67], [68].

Operating margins also showed a positive trend, especially among downstream firms where cost control measures yielded rapid returns. Statistical tests confirmed that the changes were significant at the 0.01 level across most financial metrics analyzed [69], [70], [71].

4.2 Compliance Outcomes

Compliance efficiency, measured by the time and resources required to complete SOX-mandated procedures, improved substantially. On average, the time required to complete annual internal control assessments decreased by 22%. Firms also reported fewer audit rework cycles and lower external audit adjustment rates [72], [73].

Notably, SOX 302 certifications submitted by CEOs and CFOs were completed with greater confidence and speed due to improved visibility into real-time

control data. In interviews, executives noted a "sense of assurance" enabled by anomaly detection dashboards and predictive alerts [74].

Regression models demonstrated that digital governance maturity was a significant predictor ($p < 0.001$) of SOX 404(b) audit pass rates, even after controlling for firm size, leverage, and sector sub-type [75], [76]. This underscores the causal relationship between digital governance capabilities and regulatory compliance success.

4.3 Operational Efficiency Gains

Implementation of the framework led to quantifiable improvements in audit process efficiency. Audit cycle time the number of days between the fiscal year-end and audit report issuance was reduced by an average of 11 days across all case study firms [76], [77].

Process mining tools revealed a 35% decrease in redundant control activities and a 48% reduction in manual transaction tracing tasks. These outcomes contributed to improved staff allocation and better utilization of audit team resources [78], [79].

Simulation outputs showed that in high-complexity environments (e.g., multinational upstream operations), the framework's predictive monitoring tools detected 91.4% of control break events in real time, with a false positive rate below 5% [80]. Cost per audit transaction declined by 18.3%, validating the economic value of the approach.

4.4 Comparative Results Across Firm Types

The results varied slightly based on firm size and operational complexity. Small and medium-sized enterprises (SMEs) showed faster time-to-value due to easier integration and fewer legacy systems. However, large enterprises realized greater absolute cost savings due to economies of scale [81].

Upstream firms benefited most from automated reconciliation and contract compliance modules, while downstream firms leveraged pricing analytics and customer billing validation features. Midstream firms noted improvements in asset tracking and regulatory reporting accuracy [82].

These differences emphasize the adaptability of the framework to sector-specific governance challenges and underscore its configurability.

4.5 Validation through Expert Feedback

Stakeholder workshops validated the framework's practicality and effectiveness. Participants confirmed that the framework addressed real-world pain points, especially the fragmentation of financial data and manual-intensive SOX workflows [83].

Experts rated the relevance of each framework pillar (on a scale of 1 to 5) as follows: data architecture (4.8), control automation (4.7), real-time monitoring (4.9), and compliance intelligence (4.6). Feedback emphasized the importance of integrating the framework into enterprise resource planning (ERP) systems to maximize utility [84], [85].

4.6 Summary

The results affirm that a data-driven governance framework can deliver tangible improvements in audit efficiency, SOX compliance, and financial performance within the energy sector. These findings set the stage for a broader discussion on practical implementation, stakeholder alignment, and potential areas for refinement, as presented in the next section.

V. DISCUSSION

The results from the previous section underscore the transformative potential of a data-driven financial governance framework in enhancing SOX compliance and reducing costs within energy sector audits. This discussion interprets these results through the lens of governance theory, compliance risk models, and sectoral digitalization trends, offering a deeper understanding of the implications for practice, policy, and future research.

5.1 Theoretical Implications

From a theoretical perspective, the framework reinforces the resource-based view (RBV) of the firm by demonstrating that digital capabilities such as real-time monitoring, predictive analytics, and robotic process automation (RPA) can serve as strategic resources that enhance organizational performance and regulatory compliance [86], [87]. By embedding data-driven tools into financial governance processes,

firms are effectively transforming compliance obligations into value-generating assets, thereby supporting the dynamic capabilities theory [88], [89]. Furthermore, the observed reduction in internal control deficiencies aligns with agency theory, which emphasizes the need for effective monitoring mechanisms to mitigate principal-agent conflicts [90], [91], [92]. Enhanced transparency through digital dashboards and anomaly detection tools strengthens managerial accountability, thereby addressing asymmetries in financial reporting.

5.2 Practical Implications for the Energy Sector

The framework's success in reducing audit fees, improving internal control effectiveness, and streamlining compliance procedures has practical significance for firms operating in capital-intensive, regulation-heavy sectors like energy. These findings suggest that digital transformation in financial governance is not only desirable but increasingly necessary to meet stakeholder expectations and maintain regulatory standing [95].

For instance, the 22% reduction in time spent on internal control assessments enables internal audit teams to focus on higher-value tasks, such as fraud detection and strategic advisory [95], [96]. This reallocation of resources supports the business case for digital investment, particularly when cost efficiencies are realized without compromising compliance.

Additionally, the improvements in SOX 302 and 404 certification outcomes suggest a redefinition of executive roles, where data fluency and governance literacy become essential leadership competencies. CEOs and CFOs are now required to interpret predictive analytics outputs and make real-time compliance decisions.

5.3 Sectoral Adaptability and Scalability

A notable outcome of the results section was the adaptability of the framework across firm sizes and sub-sectors. SMEs achieved faster implementation and earlier ROI due to simplified system architectures, while larger enterprises benefited from scale efficiencies [97]. This suggests that while the digital governance journey may differ based on organizational complexity, the destination enhanced compliance and cost control is universally attainable. Moreover, sector-specific gains (e.g., automated contract validation for upstream firms or billing analytics for downstream operations) validate the modular design of the framework. These differentiated benefits underline the importance of configurability in governance tools, especially in sectors with heterogeneous operational models [98].

5.4 Strategic Considerations for Implementation

While the empirical results were promising, successful implementation requires more than just technology deployment. Change management emerged as a critical enabler. Firms that achieved the most significant outcomes engaged in cross-functional collaboration between IT, finance, legal, and compliance teams. These collaborations facilitated smoother integration of tools and greater end-user adoption.

Additionally, training and capacity building were instrumental. Organizations that invested in upskilling their audit and compliance personnel in data literacy reported fewer transition challenges and quicker value realization [99]. This supports existing literature on the role of human capital in digital transformation success.

5.5 Governance and Regulatory Implications

The demonstrated link between digital maturity and SOX audit pass rates raises important questions for regulators. Should digital governance capabilities be incorporated into regulatory risk assessments? Could standardized metrics for digital readiness become part of future compliance evaluations?.

Furthermore, as the SEC and PCAOB evolve their oversight frameworks, there may be a push to formalize digital audit trails, automated control verification, and continuous assurance mechanisms as best practices. These trends would shift the governance landscape from episodic, manual verification to continuous, algorithm-assisted monitoring.

5.6 Risks and Challenges

Despite its benefits, the framework is not without challenges. Data integration across legacy systems

remains a persistent hurdle, particularly for firms with decentralized operations or recent mergers [96]. Data quality issues—such as incomplete logs, inconsistent metadata, and control duplication can compromise the reliability of predictive analytics.

Moreover, over-reliance on automated tools introduces risks related to algorithmic bias, false positives, and cybersecurity. These concerns underscore the importance of maintaining a human-in-the-loop model where expert judgment complements machine intelligence [93].

5.7 Ethical and Workforce Considerations

Automation of audit tasks raises questions about workforce displacement and the evolving role of financial professionals. While the framework reduces manual effort, it simultaneously creates demand for new skills in data science, control logic design, and compliance analytics.

The ethical deployment of these technologies also demands attention. Transparency in algorithm design, fairness in anomaly detection, and explainability of automated decisions must be prioritized to maintain stakeholder trust and avoid reputational risk.

5.8 Future Research Directions

The findings open several avenues for future research. Longitudinal studies could assess the sustainability of compliance and cost outcomes over multiple audit cycles. Comparative studies across sectors could explore the transferability of the framework to domains such as healthcare, banking, and manufacturing.

There is also a need for deeper inquiry into the interplay between governance frameworks and firm culture. How do digital tools influence ethical behavior, risk appetite, or internal audit independence?

5.9 Summary

In summary, the discussion highlights the multifaceted impact of a data-driven governance framework on SOX compliance, operational efficiency, and strategic agility in the energy sector. It affirms the framework's potential to serve as a replicable model for digital transformation in regulated industries. The final section concludes with policy and practical recommendations for stakeholders.

CONCLUSION

The deployment of a data-driven financial governance framework in the energy sector offers significant promise for enhancing Sarbanes-Oxley (SOX) compliance while simultaneously achieving cost efficiencies. As this study has demonstrated, leveraging digital tools such as real-time analytics, robotic process automation (RPA), and integrated control dashboards not only strengthens internal governance mechanisms but also reduces the complexity, time, and financial burdens associated with traditional audit processes. The outcome is a reimagined governance architecture that is responsive, scalable, and strategically aligned with organizational objectives in a highly regulated and capital-intensive industry.

The empirical findings suggest that data integration across financial processes especially when structured around modular, configurable systems enhances audit readiness and compliance reporting. This is evident in the reduced audit preparation time, increased control effectiveness, and improved SOX 302 and 404 outcomes observed across energy sector firms. Furthermore, the role of predictive analytics in early risk detection introduces a paradigm shift from reactive to proactive compliance, offering substantial strategic value for energy companies navigating complex regulatory environments [100], [101], [102], [103].

From a regulatory standpoint, this evolution in governance practices prompts a re-examination of compliance evaluation methods. Traditional audit approaches, which often rely on sampling and episodic assessments, may no longer suffice in an era of continuous monitoring and algorithm-assisted oversight. As such, regulators may need to incorporate digital maturity indices, automated evidence trails, and system-integrated controls into future versions of SOX guidelines and audit standards.

For energy firms, especially those undergoing digital transformation or operating in cross-jurisdictional contexts, the framework provides a replicable pathway toward greater financial control and regulatory alignment. Yet, it must be acknowledged that technology alone does not guarantee success. Organizational readiness, workforce capacity, and change management capabilities are equally critical. Firms that invest in cross-disciplinary training, collaborative implementation models, and ethical AI practices are more likely to realize the full benefits of this digital governance approach.

The broader implications of this study extend beyond the energy sector. As financial and operational data become increasingly interlinked, the ability to govern this data through smart, automated systems will become a defining competency in regulated industries. The interplay between data governance and financial integrity will shape how firms build trust with stakeholders, respond to crises, and future-proof their operations.

In conclusion, the proposed data-driven governance framework represents a strategic leap forward for energy sector audits under SOX mandates. It enhances not only compliance outcomes and cost management but also the strategic agility of firms operating in a volatile and scrutinized market. Future research should continue to explore how such frameworks can evolve with emerging technologies such as blockchain, quantum security, and AI ethics and how they can be adapted to other sectors with similar regulatory profiles. Ultimately, the integration of financial data governance, technological innovation, and regulatory compliance offers a powerful template for building resilient, accountable, and efficient organizations in the digital age.

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