# FLEXIBLE BUDGETING IN INNOVATION AND R&D PROJECTS: INTEGRATING TRL, PM², AND INNOVATION ECOSYSTEM GOVERNANCE

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**Abstract**. This article investigates flexible budgeting approaches for innovation and R&D projects implemented under conditions of technological uncertainty, staged technology development, and increasing ecosystem complexity. Innovation and R&D projects operate as interdependent systems characterized by iterative experimentation, evolving technological solutions, dynamic resource requirements, stakeholder interdependencies, and distributed governance structures. Under such conditions, traditional budgeting approaches based on fixed financial planning become insufficient, creating the need for adaptive budgeting systems supporting technology development, uncertainty management, and ecosystem coordination. The purpose of the study is to develop an integrated framework for flexible budgeting in innovation and R&D projects, combining TRL-oriented technology development, governance adaptation, reserve management, stage financing, and ecosystem coordination. The research has a conceptual and analytical design grounded in system, ecosystem-based, process-oriented, and risk-oriented approaches. Comparative analysis, system analysis, logical generalization, and conceptual modeling were applied to integrate project management, budgeting, TRL-oriented governance, and innovation ecosystem approaches into a unified framework. The results demonstrate that budgeting requirements differ across technology development stages and require differentiated budgeting logic, reserve structures, financing mechanisms, and governance intensity. Early-stage projects require exploratory financing with increased contingency reserves, whereas advanced stages require implementation-oriented financing and stronger governance mechanisms. The study additionally shows that innovation and R&D projects require substantial resource allocation at early stages to support experimentation and uncertainty reduction. The scientific novelty lies in the development of an integrated flexible budgeting framework connecting technology maturity, governance mechanisms, financing logic, reserve management, and ecosystem coordination. The proposed framework may be applied in R&D projects, Horizon Europe initiatives, university–industry collaborations, startup ecosystems, and collaborative innovation environments operating under technological uncertainty.

**Keywords**: flexible budgeting, technological uncertainty and risk, resource and cost management, project controlling, innovation and R&D projects, innovation ecosystems, adaptive governance.

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## Introduction

The development of the innovation economy, deep-tech entrepreneurship, and research-driven technological projects is accompanied by increasing complexity in resource and cost management. Unlike traditional projects, innovation and R&D projects are characterized by high technological uncertainty, iterative experimentation, evolving technical solutions, and limited predictability of outcomes. Under such conditions, conventional budgeting approaches based on fixed cost baselines and static financial planning become insufficient.

The problem becomes especially important in the context of Horizon Europe, EIT, and other international funding programmes, where project budgets serve not only as financial plans but also as mechanisms supporting the evaluation of implementation feasibility, technological maturity, resource adequacy, and project management capacity. In innovation projects, budgeting increasingly extends beyond accounting and financial control and becomes part of adaptive project governance.

At the same time, innovation and R&D projects are increasingly implemented within innovation ecosystems that integrate universities, startups, firms, laboratories, investors, public institutions, and other stakeholders into interconnected systems of knowledge creation and value co-production. Such ecosystems are characterized by interdependencies, collaborative resource use, stakeholder coordination, and ecosystem-related uncertainty. While these interactions improve innovation capacity and access to knowledge and infrastructure, they also increase coordination complexity, dependency risks, and the need for adaptive management mechanisms (Moore, 1993; Adner, 2006; Kubareva & Nochvai, 2025).

Under these conditions, in collaborative innovation ecosystems, budgeting performs not only a cost planning function but also acts as a mechanism aligning technological priorities, resource allocation, timelines, and stakeholder expectations. This creates the need for flexible budgeting approaches capable of integrating technology development logic, risk management, stage financing, reserve management, change management, and ecosystem coordination into a unified governance framework.

Recent studies in project management and innovation management emphasize the importance of uncertainty management in technology-intensive projects. PMBOK (Project Management Institute, 2021) and PM² (European Commission, 2023) methodologies provide structured approaches to project governance, planning, and control. Raz, Shenhar, and Dvir (2002), as well as Loch, DeMeyer, and Pich (2006), demonstrate the critical role of uncertainty and adaptive decision-making in innovation projects. Research on Technology Readiness Levels (TRL) (Mankins, 1995; Héder, 2017; Olechowski, Eppinger, & Joglekar, 2015) additionally highlights the importance of linking technology maturity with resource planning and funding decisions. Studies on adaptive and beyond-budgeting approaches (Ekholm & Wallin,

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2000; Hansen, Otley, & Van der Stede, 2003) emphasize the limitations of static budgeting systems in dynamic organizational environments.

Furthermore, innovation ecosystem studies (Moore, 1993; Adner, 2006; Etzkowitz & Leydesdorff, 2000; Kubareva & Nochvai, 2025) increasingly emphasize the role of inter-organizational coordination, collaborative governance, and stakeholder interdependencies in innovation project implementation. Ecosystem interactions generate additional coordination costs, resource dependencies, and governance complexity that require adaptive budgeting and flexible resource allocation mechanisms.

However, existing studies mainly examine project budgeting, TRL assessment, risk management, innovation ecosystems, and governance mechanisms as separate research areas. Limited attention has been paid to developing an integrated approach that combines technological maturity, adaptive governance, reserve management, ecosystem coordination, and financing logic for innovation and R&D projects operating under uncertainty.

Accordingly, the study addresses the following research questions:

RQ1: How does technological uncertainty across different TRL levels influence budgeting architecture in innovation and R&D projects?

RQ2: How can PM² governance mechanisms, reserve management, and stage financing be integrated into adaptive budgeting systems for innovation projects?

RQ3: How do innovation ecosystem interdependencies influence budgeting flexibility, coordination costs, and governance mechanisms in collaborative R&D environments?

The study has a conceptual and methodological character and aims to systematize existing approaches to TRL-oriented governance, adaptive budgeting, PM² project management, reserve management, and innovation ecosystem coordination within a unified analytical perspective.

The purpose of this article is to develop an integrated framework for flexible budgeting in innovation and R&D projects through the combination of TRL-oriented technology development, PM² governance mechanisms, stage financing, adaptive change management, and innovation ecosystem coordination. The novelty of the study lies in conceptualizing budgeting not only as a financial planning instrument but also as an adaptive governance mechanism supporting technology development and ecosystem coordination under conditions of technological uncertainty.

## Literature Review

Contemporary studies in project management consistently emphasize that innovation and R&D projects fundamentally differ from traditional projects due to higher levels of technological uncertainty, iterative experimentation, evolving stakeholder requirements, and dynamic resource needs (Raz, Shenhar, & Dvir, 2002; Loch, DeMeyer, & Pich, 2006; Project Management Institute, 2021). Unlike conventional projects, characterized by relatively stable planning assumptions, innovation environments require governance approaches that can combine structured

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coordination with continuous adaptation to changing technological and organizational conditions. From this perspective, the PMBOK and PM² methodologies provide a crucial managerial foundation for project governance, planning, monitoring, risk management, and change control in complex project environments. In addition to planning and monitoring, PM² provides governance mechanisms for managing project lifecycle phases, stakeholder engagement, role allocation, coordination, and review procedures, making it particularly relevant for collaborative and publicly funded innovation projects (Project Management Institute, 2021; European Commission, 2023). Kerzner (2022) and Meredith and Mantel (2021) additionally emphasize that increasing project uncertainty and complexity strengthen the need for adaptive managerial mechanisms and responsive decision-making.

Existing research demonstrates broad agreement regarding the importance of uncertainty as a defining characteristic of innovation projects, although scholars conceptualize its sources and implications differently. Raz, Shenhar, and Dvir (2002) primarily interpret technological uncertainty through its influence on project success and risk management effectiveness, showing that higher-risk and technologically uncertain projects require broader application of risk management practices. Tatikonda and Rosenthal (2000), in contrast, conceptualize uncertainty through technology novelty and project complexity, emphasizing their influence on task uncertainty and project execution processes. Loch, DeMeyer, and Pich (2006) further argue that projects characterized by "unknown uncertainty" cannot rely solely on predefined planning structures and instead require experimentation, trial-and-error learning, and continuous managerial adjustment. Similarly, studies on radical and discontinuous innovation demonstrate that uncertainty in innovation projects extends beyond technological issues and increasingly includes market, organizational, and resource-related dimensions (O'Connor & Rice, 2013; Rice et al., 1998). Taken together, these studies demonstrate that increasing uncertainty challenges rigid planning logic and highlights the growing importance of adaptive managerial approaches in innovation and R&D projects.

Project complexity additionally increases the need for adaptive governance and coordination mechanisms. Geraldi and Adlbrecht (2007) interpret projects as dynamic interaction systems shaped not only by formal planning structures but also by uncertainty, interdependencies, and coordination complexity. Bosch-Rekveldt et al. (2011) further demonstrate that project complexity emerges from the interaction of technical, organizational, and environmental dimensions, emphasizing that effective project governance increasingly depends on the ability to coordinate multiple actors and contextual conditions. This perspective is particularly relevant for innovation ecosystems, where technological uncertainty is combined with institutional diversity and stakeholder interdependencies.

The budgeting dimension of project management has also evolved significantly. Traditional budgeting approaches based on annual planning and fixed baselines have been increasingly criticized for insufficient adaptability in dynamic environments. Ekholm and Wallin (2000) question the effectiveness of traditional annual budgets in rapidly changing organizational settings, while Hansen, Otley, and Van der Stede

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(2003) emphasize the growing importance of adaptive budgeting systems based on continuous planning, dynamic control, and managerial flexibility. However, despite growing attention to flexible budgeting, existing approaches mainly focus on organizational settings and provide limited guidance for innovation and R&D projects characterized by technological uncertainty and staged technology development.

Technology Readiness Level (TRL) studies additionally contribute to understanding the relationship between technology maturity and project planning. Mankins (1995) introduced the TRL framework as a mechanism for assessing technological maturity in aerospace projects. Later studies by Héder (2017) and Olechowski, Eppinger, and Joglekar (2015) demonstrate the broader application of TRL in innovation management and technology governance, while also highlighting challenges associated with its implementation and interpretation across different contexts. Conrow (2011) additionally shows that TRL assessment can support risk estimation and decision-making in technology-intensive projects. Complementary innovation management approaches, such as Stage-Gate systems, further emphasize milestone validation and staged decision-making throughout innovation development processes (Cooper, 2008). Nevertheless, existing studies rarely integrate technology maturity assessment with budgeting logic, reserve allocation, and governance adaptation in innovation projects.

Studies on innovation ecosystems increasingly conceptualize innovation as a collaborative process shaped by interdependencies, coordination requirements, and distributed governance mechanisms (Adner, 2006; Granstrand & Holgersson, 2020; Kubareva & Nochvai, 2025). Collaborative innovation ecosystems are often conceptualized through Triple Helix and Quadruple Helix perspectives, which emphasize interaction between universities, industry, government, and society within interconnected innovation systems (Etzkowitz & Leydesdorff, 2000; Carayannis & Campbell, 2009). In such environments, budgeting is influenced not only by internal project activities but also by stakeholder interdependencies, shared infrastructures, collaborative resource use, and ecosystem-level coordination. This strengthens the importance of adaptive governance, flexible resource allocation, and budgeting mechanisms capable of supporting interaction between heterogeneous actors operating under uncertainty.

Overall, the reviewed literature demonstrates the growing importance of adaptive governance, interdependent coordination, and flexible management mechanisms in innovation and R&D projects operating under technological uncertainty. Existing studies additionally emphasize uncertainty management, staged financing, and ecosystem coordination as critical components of innovation project implementation. However, these approaches remain fragmented across different research streams and are rarely integrated into unified budgeting and governance models. Existing studies typically examine budgeting systems, reserve management, innovation ecosystems, and governance mechanisms separately, without sufficiently integrating technological, financial, organizational, and ecosystem dimensions of project management. To address this gap, the study develops an integrated conceptual

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framework combining technology readiness-oriented development, PM² governance mechanisms, flexible budgeting approaches, reserve management, stage financing, adaptive change management, and ecosystem coordination mechanisms. The proposed approach is based on the assumption that budgeting in innovation and R&D projects should be interpreted not only as a financial planning process but also as an adaptive governance and coordination mechanism supporting technology development and ecosystem interaction under conditions of uncertainty.

**Methodology**

The methodological basis of the study combines system, process-oriented, ecosystem-based, and risk-oriented approaches. The study has a conceptual and analytical research design aimed at integrating existing approaches to project budgeting, TRL-oriented governance, adaptive management, and innovation ecosystem coordination into a unified, flexible budgeting framework for innovation and R&D projects. The research is grounded in the assumption that budgeting in innovation and R&D projects is shaped by technology maturity, uncertainty conditions, governance requirements, and ecosystem interdependencies, demanding adaptive coordination and resource allocation mechanisms.

The study applies a combination of complementary analytical methods. Comparative analysis is used to examine PMBOK, PM², TRL-oriented approaches, and adaptive budgeting concepts to identify convergences, differences, and complementary governance mechanisms. System analysis supports the development of an integrated flexible budgeting framework by identifying interconnections between technology maturity, budgeting logic, reserve management, and ecosystem coordination. Logical generalization is applied to classify budgeting components, reserve structures, financing mechanisms, and governance requirements, while conceptual modeling is used to construct the proposed adaptive framework integrating TRL, PM², stage financing, and ecosystem coordination.

The research design is based on the integration of several analytical dimensions, including the analysis of project management and budgeting approaches, technological uncertainty and TRL-oriented governance, reserve management and stage financing mechanisms, and innovation ecosystem coordination and institutional constraints, followed by the synthesis of an integrated flexible budgeting framework.

The analytical process focused on identifying interconnections among these dimensions to develop a unified conceptual framework. The conceptual logic of the study assumes that budgeting in innovation and R&D projects is shaped by the interaction of several interrelated dimensions, including technology maturity, uncertainty conditions, project risks, timing dynamics, cost structure, ecosystem interactions, and governance requirements.

From this perspective, budgeting in innovation and R&D projects is interpreted not as a fixed financial planning mechanism but as a dynamic and adaptive process influenced by the stage of technology development, uncertainty conditions, governance requirements, and ecosystem interdependencies. The budgeting architecture therefore evolves depending on the configuration and interaction of

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technology readiness level (TRL), project risks, uncertainty level, time-related parameters, cost structure, ecosystem interactions, and stakeholder interdependencies, as well as governance and institutional constraints.

Accordingly, the proposed conceptual approach assumes that budgeting decisions in innovation and R&D projects should be aligned with technology maturity, uncertainty dynamics, resource requirements, and governance conditions throughout the project lifecycle.

The ecosystem-based approach additionally interprets innovation and R&D projects as temporary innovation ecosystems integrating heterogeneous actors, institutional logics, knowledge flows, and shared resources. This approach allows budgeting to be analyzed not only at the project level but also as a coordination mechanism supporting ecosystem interaction under uncertainty.

The study is based on the analysis and synthesis of scientific publications, international project management methodologies (PMBOK, PM²), TRL-related studies, and European innovation governance frameworks. The analytical focus is placed on innovation and R&D projects implemented within collaborative innovation ecosystems characterized by technological uncertainty, staged technology development, and adaptive governance requirements.

The proposed framework is intended to systematize existing approaches to flexible budgeting, adaptive governance, and innovation project coordination within a unified integrated model tailored to innovation and R&D projects.

**Results**

*1. Conceptual Logic of Budgeting Innovation and R&D Projects.*

The analysis of PM², TRL-oriented approaches, adaptive budgeting concepts, and innovation governance studies demonstrates that budgeting in innovation and R&D projects should be interpreted as an adaptive governance system rather than a static financial plan. In such projects, budgeting is directly connected with technology maturity, uncertainty level, reserve allocation, financing stages, and ecosystem coordination.

The proposed conceptual logic of flexible budgeting includes several interconnected elements: innovation ecosystem context, project governance, WBS–TRL–PM² integration, resource and cost planning, flexible budget formation, contingency and management reserves, stage financing, change requests, adaptive budget updates, and innovation outputs.

This logic demonstrates that budgeting in innovation and R&D projects evolves through the interaction between technological maturity, risk exposure, governance mechanisms, and ecosystem coordination. Therefore, flexible budgeting should not be limited to cost estimation or financial control. It should support decision-making, resource reallocation, stakeholder coordination, and adaptation to changes in technology development.

To illustrate the conceptual logic of the proposed approach, the study develops a structured flow of adaptive budgeting in innovation and R&D projects, integrating

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innovation ecosystem coordination, PM² governance logic, TRL-oriented development, and flexible budgeting mechanisms (Table 1).

*Table 1.* **Conceptual framework of flexible budgeting in innovation and R&D projects**

| Stage | Main budgeting logic |
|---|---|
| Innovation ecosystem | Stakeholder and resource coordination |
| Governance integration | PM²-based planning and control |
| TRL-oriented development | Synchronization of budgeting and technology maturity |
| Flexible budgeting | Adaptive resource allocation |
| Reserve management | Response to uncertainty and risks |
| Stage financing | Milestone-based funding |
| Change management | Adaptive budget updates |
| Innovation outputs | Scaling and commercialization readiness |

*Source*: compiled by the author

The results show that the conceptual logic of flexible budgeting connects technological, financial, organizational, and ecosystem dimensions of innovation project management. TRL defines the trajectory of technology maturity, while PM² provides governance mechanisms for planning, monitoring, stakeholder coordination, and change management. Reserve management and stage financing support adaptation to uncertainty and synchronize funding with milestone achievement.

Thus, budgeting in innovation and R&D projects should be conceptualized as an adaptive governance and ecosystem coordination mechanism that supports technology development, resource flexibility, and innovation scaling under uncertainty.

*2. TRL-Oriented Budgeting Logic in Innovation and R&D Projects.*

Technology maturity significantly influences budgeting architecture in innovation and R&D projects because different TRL stages are associated with different uncertainty levels, resource requirements, governance intensity, and financing structures. As technologies evolve from early-stage research toward commercialization and deployment, budgeting logic shifts from exploratory financing toward more structured implementation and coordination mechanisms.

Early TRL stages are characterized by high technological uncertainty, iterative experimentation, and limited predictability of outcomes. Under such conditions, budgeting requires flexible resource allocation and higher contingency reserves. Intermediate stages increase the importance of technical validation, testing

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coordination, and milestone-based monitoring. At advanced TRL stages, budgeting increasingly focuses on scaling, operational implementation, commercialization readiness, and ecosystem coordination. Thus, TRL should be interpreted not only as a technology maturity indicator but also as a driver of budgeting structure and governance intensity in innovation and R&D projects (Table 2).

*Table 2.* **TRL-oriented budgeting characteristics in innovation and R&D projects**

| TRL stage | Main uncertainty | Budgeting focus | Reserve logic | Governance intensity |
|---|---|---|---|---|
| TRL 1–3 | Scientific and technological uncertainty | Exploratory research funding | Higher contingency reserves | Flexible coordination and adaptive planning |
| TRL 4–6 | Technical validation and prototyping risks | Prototype development and testing budgets | Combined contingency and management reserves | Increased monitoring and milestone control |
| TRL 7–9 | Commercialization and deployment risks | Scaling, implementation, and operational budgeting | Management reserves for implementation and scaling | Formal governance and ecosystem coordination |

*Source*: compiled by the author

The findings demonstrate that budgeting architecture evolves together with technology maturity. Early TRL stages require exploratory budgeting with higher uncertainty tolerance, whereas advanced stages require stronger governance formalization, commercialization-oriented planning, and ecosystem coordination mechanisms.

*3. Flexible Budgeting and Adaptive Governance in Innovation and R&D Projects*

Traditional budgeting approaches based on fixed financial plans are poorly suited for innovation and R&D projects characterized by uncertainty, experimentation, and evolving technological solutions. Innovation projects require budgeting systems capable of adapting to changes in project scope, resource needs, stakeholder requirements, and technology development trajectories.

Within innovation ecosystems, flexible budgeting performs not only a financial planning function but also supports adaptive governance and coordination between heterogeneous actors. Budget updates, reserve adjustments, and resource reallocation become continuous processes accompanying technology development and implementation dynamics.

The proposed adaptive budgeting approach integrates governance processes, TRL-oriented planning, reserve management, stage financing, and change management into a unified budgeting system. Such integration improves synchronization between technological development and financial decision-making (Table 3).

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*Table 3*. **Traditional vs. flexible budgeting in innovation and R&D projects**

| Dimension | Traditional budgeting | Flexible budgeting |
|---|---|---|
| Planning logic | Fixed cost baseline | Adaptive and iterative planning |
| Response to uncertainty | Limited flexibility | Continuous adjustment mechanisms |
| Budget updates | Periodic or limited | Dynamic and milestone-based |
| Resource allocation | Predetermined | Adaptive resource reallocation |
| Governance logic | Financial control orientation | Adaptive governance orientation |
| Reserve use | Static reserve allocation | Dynamic reserve management |
| Financing structure | Linear budgeting | Stage financing and milestone funding |
| Stakeholder coordination | Limited integration | Continuous coordination mechanisms |

*Source*: compiled by the author

Flexible budgeting improves the ability of innovation projects to respond to technological changes, ecosystem interdependencies, and implementation uncertainty. As a result, budgeting becomes part of adaptive governance supporting innovation development, stakeholder coordination, and decision-making under changing project conditions.

*4. Reserve Management in Innovation and R&D Projects*

Reserve allocation becomes increasingly important in innovation and R&D projects because technological uncertainty and iterative experimentation significantly increase the probability of budget deviations and unforeseen resource requirements. Under such conditions, reserve structures should support not only financial stability but also adaptive project governance.

The proposed approach distinguishes between contingency reserves associated with identified technological and implementation risks and management reserves intended to address unforeseen changes, strategic adaptation needs, and unexpected governance or ecosystem conditions. Their structure and allocation depend on technology maturity, project complexity, stakeholder coordination, and ecosystem interaction intensity.

Reserve structures in innovation and R&D projects are influenced by multiple interrelated factors, including uncertainty level, technology maturity, experimentation intensity, ecosystem coordination complexity, and commercialization requirements. As uncertainty and governance complexity increase, reserve allocation mechanisms become more adaptive and increasingly oriented toward strategic coordination and implementation support (Table 4).

The results indicate that reserve management should evolve together with technology development and governance requirements. Dynamic reserve allocation improves the ability of innovation projects to respond to uncertainty, maintain continuity of development processes, and coordinate ecosystem interactions.

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*Table 4.* **Logic of reserve formation in innovation and R&D projects**

| Reserve formation factor | Budgeting implication | Reserve management logic |
|---|---|---|
| Technological uncertainty | Increased probability of budget deviations | Higher contingency reserves |
| Technology maturity growth | Transition from research to implementation | Increased management reserves |
| Iterative experimentation | Dynamic resource requirements | Flexible reserve adjustment |
| Ecosystem coordination complexity | Additional coordination and interaction costs | Governance-oriented reserve allocation |
| Commercialization and scaling | Operational and implementation risks | Strategic reserve allocation |

*Source*: compiled by the author

*5. Stage Financing in Innovation and R&D Projects*

Innovation and R&D projects rarely follow linear financing trajectories because funding needs change throughout the technology development process. Stage financing allows financial resources to be synchronized with technology maturity, milestone achievement, and risk reduction dynamics. This approach improves flexibility and reduces inefficient resource allocation during early-stage technology development. In collaborative innovation ecosystems, stage financing additionally supports coordination between research teams, investors, public funding programs, and commercialization partners.

The proposed approach integrates stage financing with TRL-oriented governance and adaptive budgeting logic. Financing priorities evolve throughout the technology development process. For analytical purposes, the study groups innovation and R&D projects into generalized development stages reflecting differences in technology maturity, financing priorities, uncertainty level, and governance requirements. Early-stage research primarily requires exploratory and validation funding, whereas prototype development and demonstration stages increasingly depend on implementation, scaling, and commercialization financing (Table 5).

*Table 5.* **Stage financing logic across stages of innovation and R&D projects**

| Project stage | Main financing objective | Budgeting logic | Governance focus |
|---|---|---|---|
| Early-stage research | Exploration and concept validation | Flexible exploratory financing | Adaptive coordination |
| Prototype development | Technical validation and testing | Milestone-based financing | Monitoring and risk control |
| Demonstration and scaling | Market readiness and deployment | Structured implementation financing | Ecosystem coordination and strategic governance |

*Source*: compiled by the author

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The analysis demonstrates that stage financing strengthens synchronization between technology development, governance processes, and resource allocation. Milestone-based financing additionally improves project control while preserving the flexibility necessary for experimentation and adaptive decision-making.

*6. Cash Flow Synchronization and Spending Dynamics in Innovation and R&D Projects*

Financial dynamics in innovation and R&D projects differ substantially from those of conventional projects because expenditure intensity, cost composition, and liquidity needs evolve unevenly throughout technology development. Unlike traditional implementation-oriented projects, where spending often gradually increases toward later phases, innovation and R&D projects may require substantial expenditures already at early stages due to experimentation, scientific validation, prototype development, and uncertainty reduction activities. As a result, budgeting systems should support not only financing allocation but also synchronization between cash flow dynamics, technology maturity, and evolving project requirements.

The structure of expenditures additionally changes across different stages of innovation development. Early-stage research typically concentrates resources on scientific personnel, experimentation, laboratory activities, exploratory testing, and specialized equipment. Prototype development stages increasingly require expenditures associated with technical validation, prototyping, testing infrastructure, stakeholder coordination, and iterative modifications. At advanced stages, expenditure structures shift toward implementation, demonstration, commercialization preparation, operational integration, and ecosystem coordination activities. Consequently, innovation and R&D projects are characterized not only by changing expenditure intensity but also by evolving cost structures throughout the project lifecycle, which may vary considerably depending on technology domain and implementation context.

Cash flow patterns in innovation and R&D projects evolve together with technology development, uncertainty conditions, financing arrangements, and ecosystem interactions. Expenditures may remain irregular and difficult to predict during exploratory stages, while later stages often require stronger synchronization between financing schedules, implementation timelines, partnership coordination, and commercialization objectives. Under such conditions, effective budgeting requires mechanisms capable of maintaining liquidity flexibility while ensuring continuity of technology development and implementation processes (Table 6).

The proposed framework highlights that financial dynamics in innovation and R&D projects evolve together with technology maturity, expenditure composition, and implementation requirements. Adaptive synchronization of cash flows, therefore, becomes critical not only for financial stability but also for maintaining experimentation continuity, supporting technology validation, and coordinating implementation and commercialization activities within collaborative innovation ecosystems.

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*Table 6*. **Cash flow synchronization and spending dynamics across innovation and R&D project stages**

| Project stage | Budget expenditure profile | Dominant cost structure | Cash flow dynamics | Financial management implications |
|---|---|---|---|---|
| Early-stage research | Potentially intensive but highly uncertain expenditures | Research personnel, experimentation, laboratory activities, scientific equipment | Irregular and difficult-to-predict spending | Flexible financing and liquidity flexibility |
| Prototype development | Milestone-dependent and technically intensive expenditures | Prototyping, testing, technical validation, coordination activities | Cyclical and milestone-linked cash flows | Budget updates and reserve adjustment |
| Demonstration and scaling | More structured implementation-oriented expenditures | Demonstration, deployment, commercialization preparation, ecosystem coordination | More predictable but coordination-intensive financial flows | Stronger financial synchronization and implementation control |

*Source*: compiled by the author

*7. Institutional Constraints and Governance Conditions in Innovation and R&D Budgeting*

Innovation and R&D projects implemented within international funding programs and collaborative ecosystems operate under multiple institutional and governance constraints. Budgeting decisions are influenced not only by internal project requirements but also by donor regulations, reporting procedures, eligibility rules, partnership agreements, and governance standards established by funding institutions.

In funding programmes such as Horizon Europe, EIT, and other international R&D initiatives, budgeting systems must simultaneously support flexibility and compliance. This creates tensions between adaptive resource allocation and formal financial accountability requirements. Innovation projects, therefore, require governance mechanisms capable of balancing experimentation, uncertainty management, stakeholder coordination, and institutional control.

Institutional constraints additionally influence reserve structures, financing procedures, procurement processes, reporting intensity, and change management mechanisms. Under collaborative ecosystem conditions, governance complexity increases because multiple actors operate within different organizational logics, administrative procedures, and strategic priorities.

The proposed framework integrates adaptive budgeting logic with institutional governance requirements and ecosystem coordination mechanisms. Such integration improves alignment between project implementation dynamics, financial compliance, and stakeholder interaction processes.

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*Table 7.* **Institutional constraints influencing budgeting in innovation and R&D projects**

| Institutional dimension | Budgeting implications | Governance consequences |
|---|---|---|
| Funding program regulations | Restricted cost eligibility and reporting rules | Increased financial control |
| Partnership agreements | Shared resource allocation and coordination requirements | Multi-actor governance |
| Procurement and compliance procedures | Administrative budgeting constraints | Formal monitoring mechanisms |
| Donor accountability requirements | Documentation and audit obligations | Strengthened reporting intensity |
| Ecosystem coordination conditions | Coordination and communication costs | Distributed governance structures |

*Source*: compiled by the author

The analysis demonstrates that institutional constraints significantly shape budgeting architecture in innovation and R&D projects. Effective budgeting, therefore, requires the integration of adaptive governance mechanisms with formal compliance requirements, ecosystem coordination processes, and institutional accountability procedures. Such integration improves alignment between project implementation dynamics, financial control, stakeholder interaction, and regulatory obligations operating under conditions of technological uncertainty.

*8. Innovation Ecosystem Coordination in Flexible Budgeting*

Innovation and R&D projects are increasingly implemented within collaborative innovation ecosystems that integrate universities, firms, startups, research laboratories, investors, public institutions, and intermediary organizations. In such environments, budgeting extends beyond internal project planning and becomes part of ecosystem coordination and multi-actor governance.

Ecosystem interactions influence budgeting through stakeholder interdependencies, shared infrastructures, distributed resources, joint activities, and collaborative decision-making processes. As a result, budgeting systems should support coordination between heterogeneous actors operating under different institutional logics, financing conditions, and implementation priorities.

In collaborative ecosystems, additional budgeting complexity emerges from coordination costs, asynchronous financing structures, communication processes, resource-sharing mechanisms, and varying governance requirements among ecosystem participants. Flexible budgeting, therefore, becomes necessary for maintaining coordination, adapting to changing ecosystem conditions, and supporting continuity of technology development.

The proposed approach interprets innovation projects as temporary innovation ecosystems characterized by dynamic stakeholder interaction, resource exchange, and adaptive governance processes. Within this logic, budgeting functions not only as a

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financial management mechanism but also as a coordination instrument supporting ecosystem integration and innovation scaling.

Based on the reviewed innovation ecosystem literature and the analytical logic of the proposed framework, several ecosystem-related dimensions influencing budgeting and coordination requirements in innovation and R&D projects are identified (Table 8).

*Table 8.* **Ecosystem coordination dimensions affecting budgeting in innovation and R&D projects**

| Ecosystem dimension | Budgeting implications | Coordination requirements |
|---|---|---|
| Multi-actor participation | Distributed resource allocation | Stakeholder coordination |
| Shared infrastructure | Joint cost structures | Resource synchronization |
| Partnership interaction | Coordination and communication costs | Governance integration |
| Diverse funding sources | Asynchronous financing flows | Adaptive financial planning |
| Ecosystem interdependencies | Increased uncertainty and dependency risks | Flexible governance mechanisms |

*Source*: compiled by the author

Adaptive budgeting mechanisms strengthen the capacity of ecosystem actors to coordinate resources, synchronize financing processes, manage interdependencies, and support innovation implementation under conditions of uncertainty and institutional complexity.

*9. Integrated Framework of Flexible Budgeting in Innovation and R&D Projects*

The conducted analysis demonstrates that effective budgeting in innovation and R&D projects requires the integration of technological, financial, governance, institutional, and ecosystem dimensions within a unified adaptive framework. Traditional budgeting approaches based on fixed financial planning become insufficient under conditions of technological uncertainty, iterative experimentation, staged technology development, stakeholder interdependencies, and dynamic resource requirements. Under such conditions, budgeting should be interpreted not only as a financial planning mechanism but also as an adaptive governance and coordination system supporting technology development and project implementation.

The proposed integrated framework combines contextual project conditions, TRL-oriented technology development, adaptive budgeting mechanisms, PM² governance logic, and ecosystem coordination processes into a coherent and interconnected budgeting architecture. Within this framework, budgeting evolves together with technology maturity and uncertainty dynamics, allowing governance mechanisms, financing structures, reserve allocation, and resource management practices to adapt throughout the project lifecycle.

The framework begins with a set of contextual drivers shaping budgeting architecture in innovation and R&D projects, including technological uncertainty,

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institutional and regulatory conditions, market and commercialization dynamics, and ecosystem complexity. These factors are conceptualized through four interconnected UIME dimensions: technological uncertainty (U), institutional and regulatory environment (I), market and commercialization dynamics (M), and ecosystem complexity (E). Together, the UIME dimensions influence uncertainty levels, governance requirements, stakeholder interdependencies, and implementation constraints, shaping budgeting decisions in collaborative innovation environments.

TRL-oriented technology development constitutes the central logic of the framework and functions as a key driver of budgeting adaptation. Different stages of technology maturity require differentiated budgeting priorities, reserve structures, financing intensity, and governance mechanisms. Early-stage projects are characterized by exploratory and experimentation-oriented budgeting, while advanced stages increasingly require implementation coordination, commercialization readiness, and structured financial management. At the same time, iterative learning and feedback mechanisms allow budgeting logic to remain adaptive under changing technological conditions.

The flexible budgeting architecture integrates five interconnected components: budgeting logic, reserve management, stage financing, financial flow synchronization, and resource and cost management. These components operate as an interdependent system supporting adaptive planning, milestone-based financing, reserve adjustment, resource flexibility, and synchronization between technology development and financial decision-making. Rather than functioning independently, budgeting mechanisms continuously interact to support responsiveness under conditions of uncertainty and evolving project requirements.

The governance dimension of the framework incorporates key PM² elements, including lifecycle-based governance, stakeholder coordination mechanisms, governance structures, monitoring and review procedures, and adaptive governance intensity. In this context, PM² contributes not only to planning and control logic but also to role distribution, coordination mechanisms, and adaptive oversight, particularly relevant for collaborative innovation and publicly funded R&D projects.

The framework additionally incorporates an ecosystem coordination layer reflecting the increasing importance of stakeholder interdependencies, shared infrastructures, collaborative coordination, ecosystem risks, and commercialization pathways in innovation projects. Within collaborative innovation ecosystems, budgeting performs not only a financial function but also supports coordination between heterogeneous actors operating under different institutional and organizational conditions.

Finally, the proposed framework integrates a feedback loop connecting monitoring, evaluation, budget adjustment, and governance modification mechanisms. This dynamic logic enables budgeting systems to respond to uncertainty and changing project conditions while maintaining alignment between technology development, governance mechanisms, and resource allocation. Figure 1 summarizes the proposed integrated framework of flexible budgeting in innovation and R&D projects.

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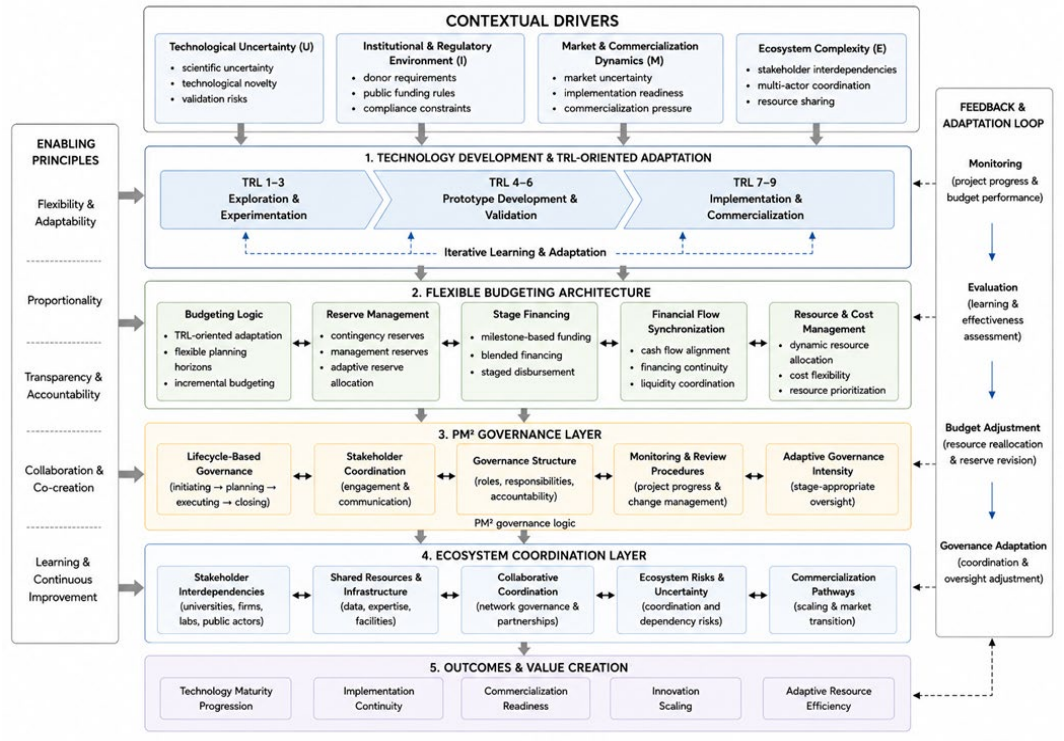


Figure 1 – Integrated framework of flexible budgeting in innovation and R&D projects

*Source*: compiled by the author

The proposed framework additionally enables the operationalization of budgeting decisions by linking technology maturity, uncertainty conditions, governance requirements, and ecosystem interactions with corresponding budgeting and coordination mechanisms.

*10. Illustrative Operationalization of the Framework in Innovation and R&D Projects*

To enhance the practical interpretability of the proposed framework, the study also illustrates how flexible budgeting logic can support decision-making under various conditions characteristic of innovation and R&D projects. Rather than functioning as a prescriptive budgeting model, the framework is intended to guide budgeting adaptation depending on technology maturity, uncertainty conditions, governance requirements, institutional constraints, and ecosystem interdependencies. In practice, budgeting decisions emerge from the interaction of several project conditions that influence financing priorities, reserve allocation, governance intensity, and coordination requirements.

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To demonstrate the practical application of the framework, Table 9 presents illustrative examples of how different project conditions may trigger corresponding budgeting and governance responses in innovation and R&D environments.

*Table 9.* **Illustrative operationalization of the flexible budgeting framework in innovation and R&D projects**

| Project condition | Key project conditions | Budgeting response | Governance response |
|---|---|---|---|
| Early-stage deep-tech project with high technological uncertainty | High uncertainty; TRL 1–3; experimentation intensity | Flexible exploratory budgeting; increased contingency reserves | Adaptive coordination and lower governance formalization |
| Prototype validation delays or unexpected technical challenges | TRL transition; technical uncertainty; implementation risks | Budget reallocation; reserve adjustment; milestone revision | Increased monitoring and review procedures |
| Inclusion of additional ecosystem partners | Ecosystem complexity; stakeholder interdependencies | Budget adjustment for coordination and communication costs | Stronger stakeholder coordination mechanisms |
| Transition toward implementation and commercialization | TRL 7–9; commercialization dynamics | Scaling-oriented financing; increased management reserves | Formal governance and implementation oversight |
| Changes in donor or institutional requirements | Institutional constraints; compliance conditions | Budget restructuring according to eligibility requirements | Stronger compliance monitoring and governance adaptation |

*Source:* compiled by the author.

The illustrative operationalization demonstrates that the proposed framework may support budgeting adaptation by linking project conditions with corresponding responses in financing, reserves, governance, and coordination. Thus, budgeting in innovation and R&D projects should be interpreted not as a static financial planning instrument but as a flexible decision-support mechanism evolving together with technology development, uncertainty conditions, and ecosystem interaction.

**Discussion**

The study demonstrates that effective budgeting in innovation and R&D projects requires continuous adaptation to technology maturity, uncertainty conditions, governance requirements, and ecosystem interdependencies. The proposed framework suggests that budgeting architecture evolves together with technology development and therefore cannot rely solely on fixed financial baselines or static planning assumptions. Instead, innovation projects require budgeting systems capable of supporting experimentation, dynamic resource allocation, and adaptive decision-making throughout the project lifecycle. The findings further indicate that, unlike conventional project settings where resource intensity typically increases during implementation, innovation and R&D projects often require substantial resource

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commitment already at early stages to support experimentation, technology validation, uncertainty reduction, and specialized research activities.

The proposed framework contributes to the growing body of research on project governance and adaptive budgeting by integrating technological maturity, governance mechanisms, financing structures, reserve management, and ecosystem coordination within a unified analytical perspective. Previous studies primarily examined project budgeting, uncertainty management, TRL assessment, governance systems, and ecosystem coordination as relatively separate research streams. In contrast, the proposed framework demonstrates how these dimensions interact and jointly shape budgeting architecture in innovation and R&D projects operating under uncertainty.

The findings are consistent with existing studies emphasizing the limitations of static budgeting systems in dynamic and uncertain environments (Ekholm & Wallin, 2000; Hansen, Otley, & Van der Stede, 2003), while extending these approaches through the integration of TRL-oriented development logic and adaptive governance mechanisms. Similarly, the results support prior research highlighting the importance of uncertainty management and flexible decision-making in technology-intensive projects (Raz, Shenhar, & Dvir, 2002; Loch, DeMeyer, & Pich, 2006), while additionally demonstrating that uncertainty should be interpreted not only as a risk management challenge but also as a factor shaping budgeting architecture, reserve allocation, financing intensity, and governance requirements across technology development stages.

The study also contributes to innovation ecosystem research by demonstrating that budgeting in collaborative R&D environments extends beyond internal financial planning and increasingly functions as a coordination mechanism supporting stakeholder interaction, shared infrastructures, and distributed governance processes. This finding is particularly relevant for collaborative innovation programmes such as Horizon Europe, EIT initiatives, university–industry partnerships, and deep-tech ecosystems, where multiple actors operate under heterogeneous institutional conditions and interdependent implementation processes.

From a practical perspective, the proposed framework may support budgeting adaptation in collaborative innovation and R&D environments characterized by technological uncertainty, staged technology development, and multi-stakeholder interaction. The framework may be particularly relevant in contexts where budgeting decisions require adaptive resource allocation, milestone-based financing, reserve management, and coordinated governance under changing implementation conditions. Future research may focus on empirical testing of the framework across different collaborative innovation settings and technology domains. Comparative studies may additionally examine how budgeting architecture evolves under different funding conditions, ecosystem configurations, and technology maturity trajectories.

## Conclusions

The study demonstrates that traditional budgeting approaches based on fixed financial planning are insufficient for innovation and R&D projects operating under conditions of technological uncertainty, iterative development, stakeholder

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interdependencies, and ecosystem complexity. In contrast, innovation projects require flexible budgeting systems capable of supporting dynamic resource allocation, stage financing, reserve management, ecosystem coordination, and continuous governance adaptation throughout the project lifecycle.

The results demonstrate that budgeting in innovation and R&D projects evolves together with technology maturity, uncertainty conditions, governance requirements, and ecosystem interactions. The findings additionally indicate that expenditure structures and cash flow dynamics evolve across technology development stages, requiring flexible synchronization between financing, liquidity needs, and implementation priorities. TRL-oriented development influences financing structures, reserve allocation logic, and governance requirements, while collaborative innovation ecosystems increase the importance of coordination mechanisms, stakeholder synchronization, and responsive decision-making.

The scientific contribution of the study lies in the development of an integrated framework for flexible budgeting in innovation and R&D projects that combines TRL-oriented technology development, PM² governance mechanisms, flexible budgeting architecture, reserve management, stage financing, financial flow synchronization, ecosystem coordination, and adaptive governance within a unified analytical model. Unlike traditional budgeting approaches, the proposed framework conceptualizes budgeting as a dynamic governance and coordination mechanism evolving together with technology maturity, uncertainty conditions, and project implementation requirements.

From a practical perspective, the proposed framework may support budgeting and governance processes in Horizon Europe, EIT, university–industry collaborations, startups, research laboratories, scientific teams, deep-tech environments, and other collaborative innovation initiatives characterized by staged technology development and technological uncertainty. The illustrative operationalization additionally demonstrates how budgeting decisions may be aligned with technology maturity, governance requirements, institutional constraints, and ecosystem coordination conditions in practice.

At the same time, the study has a conceptual and analytical character and focuses on framework development through analytical synthesis rather than empirical testing. Empirical validation of the proposed framework, therefore, remains an important direction for future research. The proposed framework should be interpreted as a conceptual governance model based on analytical synthesis rather than quantitative estimation or comparative project evaluation. Its applicability may vary depending on technological, institutional, and ecosystem contexts. Future research may focus on empirical testing of the framework in innovation and R&D projects and comparative analysis across different innovation ecosystems and funding programmes.

**Author Declarations**

**Author Contributions**:

Iryna Kubareva — Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization.

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The author was responsible for all aspects of the study, including conceptualization, methodology development, analysis, framework design, and manuscript preparation. The author has read and approved the final version of the manuscript.

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**Data Availability**: No empirical datasets were generated or analyzed during the current study. Additional materials related to the conceptual framework are available from the author upon reasonable request.

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## ГНУЧКЕ БЮДЖЕТУВАННЯ В ІННОВАЦІЙНИХ ТА R&D-ПРОЄКТАХ: ІНТЕГРАЦІЯ TRL, PM² ТА УПРАВЛІННЯ ІННОВАЦІЙНИМИ ЕКОСИСТЕМАМИ

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**Анотація.** У статті досліджуються підходи до гнучкого бюджетування інноваційних та R&D-проєктів, що реалізуються в умовах технологічної невизначеності, поетапного розвитку технологій та зростаючої складності інноваційних екосистем. Інноваційні та R&D-проєкти характеризуються ітеративним експериментуванням, розвитком технологічних рішень, динамічними потребами в ресурсах і взаємозалежністю стейкхолдерів, що ускладнює координацію та підвищує рівень невизначеності. За таких умов традиційні підходи до бюджетування, засновані на фіксованому фінансовому плануванні, стають недостатніми. Метою дослідження є розроблення інтегрованого фреймворку гнучкого бюджетування інноваційних та R&D-проєктів шляхом поєднання планування ресурсів, управління резервами, координації фінансування та механізмів управління на різних стадіях розвитку технологій. Дослідження має концептуально-аналітичний характер і ґрунтується на системному, екосистемному, процесному та ризикоорієнтованому підходах. У роботі використано порівняльний аналіз, системний аналіз, логічне узагальнення та концептуальне моделювання для інтеграції підходів до проєктного управління, бюджетування, TRL-орієнтованого управління та координації інноваційних екосистем у межах єдиного аналітичного фреймворку. Результати дослідження демонструють, що вимоги до бюджетування суттєво відрізняються залежно від стадії розвитку технологій і потребують диференційованої логіки бюджетування, різних резервних структур, фінансових механізмів та інтенсивності управління. Початкові стадії інноваційних та R&D-проєктів потребують високогнучкого фінансування зі збільшеними резервами на непередбачувані витрати, тоді як пізніші стадії вимагають структурованого фінансування впровадження та посилених механізмів екосистемного управління.
Наукова новизна полягає у розробленні інтегрованого фреймворку гнучкого бюджетування, який поєднує TRL-орієнтований розвиток технологій, механізми управління, логіку фінансування, резервний менеджмент і координацію інноваційних екосистем. Запропонований фреймворк може бути застосований у R&D-проєктах, проєктах Horizon Europe, університетсько-бізнесових партнерствах, стартап-екосистемах та інших колаборативних інноваційних середовищах.

***Ключові слова*:** гнучке бюджетування, технологічна невизначеність та ризики, управління ресурсами і витратами, проєктний контролінг, інноваційні та R&D-проєкти, інноваційні екосистеми, адаптивне управління.

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