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Table of Contents

Biological Sciences

Legal Sciences

The Righteous Use of Force under International Law

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Abstract

The prohibition of force is one of the fundamental cornerstones of modern international law. This norm is not only enshrined in the UN Charter, but is also recognized as a jus cogens rule, which means that no agreement can affect it and states have no right to ignore it. This prohibition has played an important role in maintaining the stability of the international system, preventing aggressive wars, and defining the legal framework of international relations.

Yet international law does not treat the prohibition as absolute. Certain circumstances permit states to resort to force lawfully, most notably in cases of self-defense and when authorized by the United Nations Security Council. Over time, new doctrines have emerged — humanitarian intervention, anticipatory self-defense, the protection of nationals abroad, and, more recently, responses to cyberattacks.

Over time, international practice has given rise to new debates and doctrines that go beyond the existing framework. The idea of humanitarian intervention, which aims to protect the population from mass crimes; the concept of preventive defense, which seeks to justify the use of force in the face of the reality and inevitability of the threat with legal arguments; as well as the protection of citizens abroad and the ability to respond to cyber attacks in the modern era—all these pose a challenge to traditional norms.

The study of these issues is important because they reveal the tension between three essential values: sovereignty, security, and human rights. It is against this background that the dynamics of modern international law are formed and the boundaries of the legitimacy of the use of force are constantly questioned.

This article examines the historical development, legal framework, and contemporary controversies surrounding the righteous use of force under international law. It evaluates both established principles and contested practices, highlighting the tension between sovereignty, security, and human rights.

Key words: International Law, sovereignty, security, and human rights.

Introduction

War, with its attendant destruction and human suffering, has long prompted legal inquiry into the circumstances under which the use of armed force may be considered lawful. The prohibition of force in Article 2(4) of the Charter of the United Nations (UN Charter) represents a cornerstone of international relations. At the same time, international law provides exceptions that authorize force, primarily in the form of self-defense and measures sanctioned by the UN Security Council.

The question of “righteous” use of force remains one of the most debated issues in contemporary international law. State practice often reveals divergent interpretations: while some

governments cling to a restrictive understanding of the Charter framework, others attempt to broaden the legal justifications for force to address new security threats. Against this backdrop, this article explores the historical foundations, legal principles, and emerging challenges surrounding the lawful use of force by states.

Historical Development of the Concept of Force

The history of international law demonstrates a gradual evolution from permissive to restrictive attitudes toward war. In the ancient world, force was regarded as a natural instrument of policy. Thucydides, in his account of the Peloponnesian War, described interstate relations as governed by power rather than law.[1]

The Christianization of the Roman Empire gave rise to the "just war" doctrine. St. Augustine condemned aggression as illegitimate, while St. Thomas Aquinas articulated three conditions for a just war: proper authority, just cause, and right intention.[2] Later, Hugo Grotius emphasized that war could only be justified as a last resort when peaceful means failed.[3]

The Peace of Westphalia (1648) and the subsequent rise of state sovereignty gradually eroded the just war concept. By the 19th century, war was largely accepted as a sovereign right. Attempts to regulate it emerged in the Hague Conventions of 1899 and 1907, which sought to limit methods of warfare but did not outlaw war itself.

A turning point came with the Covenant of the League of Nations (1919), which obliged members to seek arbitration before resorting to war. This trajectory culminated in the Kellogg-Briand Pact of 1928, where states renounced war "as an instrument of national policy.[4] However, these instruments lacked effective enforcement, as the outbreak of the Second World War tragically demonstrated.

With the creation of the United Nations in 1945, the prohibition of force was codified in binding form, and the use of force became lawful only in exceptional cases.

The UN Charter Framework

Article 2(4) of the UN Charter obliges all states to refrain from "the threat or use of force against the territorial integrity or political independence of any state.[5] This provision, widely regarded as customary international law and jus cogens, underpins the prohibition of aggression.

The Charter recognizes two principal exceptions:

1. Self-defense (Article 51) — States retain an "inherent right" of individual or collective self-defense if an armed attack occurs.

2. Security Council authorization (Chapter VII) — The Security Council may determine threats to peace and authorize military measures to restore international security.

Together, these provisions establish a collective security system intended to replace unilateral uses of force. Yet ambiguities remain regarding the scope of "armed attack," proportionality, necessity, and the legality of emerging doctrines not explicitly mentioned in the Charter.

[1] Thucydides, History of the Peloponnesian War, trans. R. Warner (Penguin Classics, 1972), p. 48.

[2] St. Thomas Aquinas, Summa Theologica, II-II, Q.40, Art.1, in A. Pegis (ed.), Basic Writings of Saint Thomas Aquinas, Vol. 2 (New York: Random House, 1945), pp. 682–684.

[3] Hugo Grotius, De Jure Belli ac Pacis (On the Law of War and Peace), Book II, trans. F.W. Kelsey (Oxford: Clarendon Press, 1925), p. 178.

[4] General Treaty for the Renunciation of War (Kellogg–Briand Pact), 27 August 1928, 94 LNTS 57.

[5]. Charter of the United Nations, 26 June 1945, 1 UNTS XVI, Art. 2(4).

Self-Defense

Origins in Customary International Law

The modern law of self-defense traces its roots to the Caroline incident of 1837. In correspondence between U.S. Secretary of State Daniel Webster and British officials, the necessity of self-defense was defined as "instant, overwhelming, leaving no choice of means, and no moment for deliberation," and the response had to be proportionate.[6] This "Caroline formula" remains influential.

Article 51 of the UN Charter

Article 51 preserves the "inherent right" of self-defense if an armed attack occurs, pending Security Council action. The International Court of Justice (ICJ) confirmed in the Nicaragua case (1986) that self-defense exists both under customary international law and the Charter.[7]

The right of self-defense is subject to strict conditions:

Response to armed attack — Minor incidents, such as border skirmishes, do not qualify.[8]
Necessity — Force must be the last resort.
Proportionality — Responses must be commensurate with the scale of attack.
Reporting — States must inform the Security Council of self-defense actions.
Termination — Force must cease when the Security Council effectively addresses the situation.

Collective Self-Defense

Article 51 also permits collective self-defense, where states may assist a victim of aggression. The Kuwait crisis of 1990, when coalition forces acted in defense of Kuwait following Iraq's invasion, represents a clear example of lawful collective self-defense.[9]

Security Council Authorization

Under Chapter VII, the Security Council may determine the existence of a threat to peace, breach of peace, or act of aggression, and authorize enforcement measures. Resolutions 678 (1990) and 1973 (2011), authorizing action in Iraq and Libya respectively, exemplify such mandates.

The Council's discretion is wide, and its political nature sometimes limits effectiveness. Nevertheless, Security Council authorization remains the most widely accepted legal basis for the use of force beyond self-defense.

Other Claimed Justifications for Force

Humanitarian Intervention

The notion of humanitarian intervention — using force to prevent atrocities — remains highly contested. NATO's 1999 intervention in Kosovo, undertaken without Security Council approval, was described by the Independent International Commission on Kosovo as "illegal but

[6] Caroline Correspondence (Exchange of Letters between Lord Ashburton and Daniel Webster, 1837–1842), reproduced in J.B. Moore (ed.), Digest of International Law, Vol. II (Washington D.C.: U.S. Government Printing Office, 1906), pp. 412–414.
[7] Military and Paramilitary Activities in and against Nicaragua (Nicaragua v. United States of America), ICJ Reports 1986, p. 14 at 94–95, paras. 176–179.
[8] . Ibid., at 103–104, para. 195 (distinguishing minor frontier incidents from "armed attacks").
[9] United Nations Security Council Resolution 678, 29 November 1990, UN Doc. S/RES/678 (1990).

legitimate."[10] While supporters invoke moral imperatives, critics argue that humanitarian intervention contravenes Article 2(4).

Anticipatory or Pre-Emptive Self-Defense

States such as the United States and Israel have occasionally claimed a right to pre-emptive strikes. Israel's 1981 attack on Iraq's Osirak nuclear reactor and the U.S. doctrine after 9/11 exemplify this position.[11] Most scholars, however, view anticipatory self-defense as incompatible with Article 51, which requires an actual armed attack.

Protection of Nationals Abroad

Some states argue that force may be used to rescue nationals facing imminent danger abroad, as in Israel's 1976 Entebbe operation. Yet the legality of this practice remains uncertain, as it often infringes upon territorial sovereignty.[12]

Responses to Non-State Actors

The rise of terrorism and armed groups has complicated the framework. After 9/11, the Security Council recognized the right of self-defense against non-state actors, paving the way for military action in Afghanistan.[13] The ICJ has nonetheless cautioned that not all acts by non-state groups amount to an "armed attack."

Cyberattacks

In the digital age, cyber operations capable of causing physical destruction raise new questions. While no consensus exists, some scholars argue that large-scale cyberattacks may constitute an "armed attack" under Article 51.[14]

Case Studies

Kosovo (1999): NATO intervention without Security Council approval remains a benchmark for the debate on humanitarian intervention.

Iraq–Kuwait (1990–91): A clear case of collective self-defense with Security Council authorization.

Israel–Osirak (1981): Condemned as unlawful anticipatory self-defense.

Afghanistan (2001): Recognized as self-defense against terrorism, marking a new precedent.

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[10] Independent International Commission on Kosovo, The Kosovo Report: Conflict, International Response, Lessons Learned (Oxford: Oxford University Press, 2000), p. 186.

[11] United Nations Security Council Resolution 487, 19 June 1981, UN Doc. S/RES/487 (1981), condemning Israel's attack on the Osirak nuclear reactor.

[12] Yoram Dinstein, War, Aggression and Self-Defence, 5th ed. (Cambridge: Cambridge University Press, 2011), pp. 233–236.

[13] United Nations Security Council Resolution 1368, 12 September 2001, UN Doc. S/RES/1368 (2001), recognizing the inherent right of self-defense in response to the 9/11 terrorist attacks.

[14] Michael N. Schmitt, "Computer Network Attack and the Use of Force in International Law: Thoughts on a Normative Framework," (1999) 37 Columbia Journal of Transnational Law 885, at 889–892.

Contemporary Challenges

Modern threats such as terrorism, cyberwarfare, and mass human rights violations challenge the rigidity of the Charter framework. States continue to stretch legal doctrines to justify force, raising concerns about erosion of the prohibition in Article 2(4). At the same time, the principle of sovereignty remains a bulwark against unfettered intervention.

The ongoing debate reflects a struggle between preserving the integrity of international law and adapting it to evolving realities.

Conclusion

The legitimacy of the use of force in international law is built on clear principles, but its implementation in practice creates a complex and contradictory picture. The UN Charter unequivocally establishes that force may be used only in self-defense or with the permission of the Security Council. This framework still retains its relevance, as it provides a legal basis for international relations and limits the legitimacy of aggression.

Nevertheless, the practice of states demonstrates a constant attempt to expand these exceptions. The discourse of humanitarian intervention is often presented as a necessity to protect human life and dignity, but in reality it can serve political and strategic interests. The theory of preventive defense seeks to change the temporal boundaries of the use of force, although this creates the risk that the perception of subjective threat becomes a justification for aggression. The protection of citizens abroad and in cyberspace The issues of defense further intensify the discussion, as they concern areas where legal norms are still in the process of being formed.

Against the background of these challenges, three principles are given particular importance: necessity, proportionality and collective oversight. Only under these conditions is it possible to have legal and political legitimacy for the use of force. Otherwise, there is a risk that international law will lose one of its main achievements—the strict prohibition of the use of force—and the international system will return to a reality where force determines law.

Ultimately, the question of the use of force is not only legal, but also deeply political. Its legitimacy depends on the extent to which the international community can strike a balance between legal principles and real security needs. Without this balance, neither international peace nor human rights can be maintained.

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Geographic Sciences

MORPHOMETRİC ANALYSİS OF THE DEEP DİSSECTİON OF THE BOLGARCHAY BASİN

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Abstract

This study summarizes the results of morphometric investigations conducted to assess the relief conditions of the Bolgarchay basin and analyzes its main quantitative indicators. These data hold scientific significance as factual material for determining the degree of relief dissection in the area and can be utilized for economic planning purposes.

Keywords: relief, slope, inclination, morphometric, meter, depth, dissection

The morphometric analysis of the surface's deep dissection in the studied area is of great importance for understanding its modern dynamics and eco-geomorphological conditions. Morphometric studies are typically conducted using large-scale topographic maps through measurements and calculations performed in controlled conditions, resulting in specialized maps for each relief element [1].

Based on the measurements and calculations, specialized maps are created, including horizontal dissection maps, deep dissection maps, surface slope maps, and base surface maps [2].

The morphometric analysis of the Earth's surface relief has been addressed by scholars such as N.M. Volkov, A.S. Devdariani, R.X. Piriyev, M.M. Mehbaliyev, R.S. Chalov, and others. The deep dissection of slopes, one of the key morphometric indicators of the relief in the studied area, is significant due to its impact on human economic activities and the ecological conditions of the environment. Taking these factors into account, the study was conducted using GIS technology. For this purpose, a 1:100,000-scale topographic map of the basin and research works dedicated to the morphometric analysis of relief and its environment-forming functions were utilized [3, 4, 5].

In studying the deep dissection of slopes, a traditional method was employed and refined based on cartographic-morphometric analysis to create a deep dissection map. The area of the slopes was measured using the ArcGIS ArcMap Version 9.3 (2009) software.

The studied Bolgarchay basin covers an area of 307.60 km², with a maximum elevation of 1,159.5 meters (Limar Mountain).

The analysis of the deep dissection map of the slopes was carried out in the following sequence:

1. Using the 1:100,000-scale topographic map, the boundaries of the slopes were delineated based on various degrees of watershed lines and the network of valleys and ravines.
2. The highest and lowest elevations within each slope were identified and recorded.
3. The average value of deep dissection was determined for each slope and recorded accordingly.

In the compiled map, the deep dissection of each elementary basin within the Bolgarchay basin was categorized with a 200-meter interval and color-coded (Figure 1).

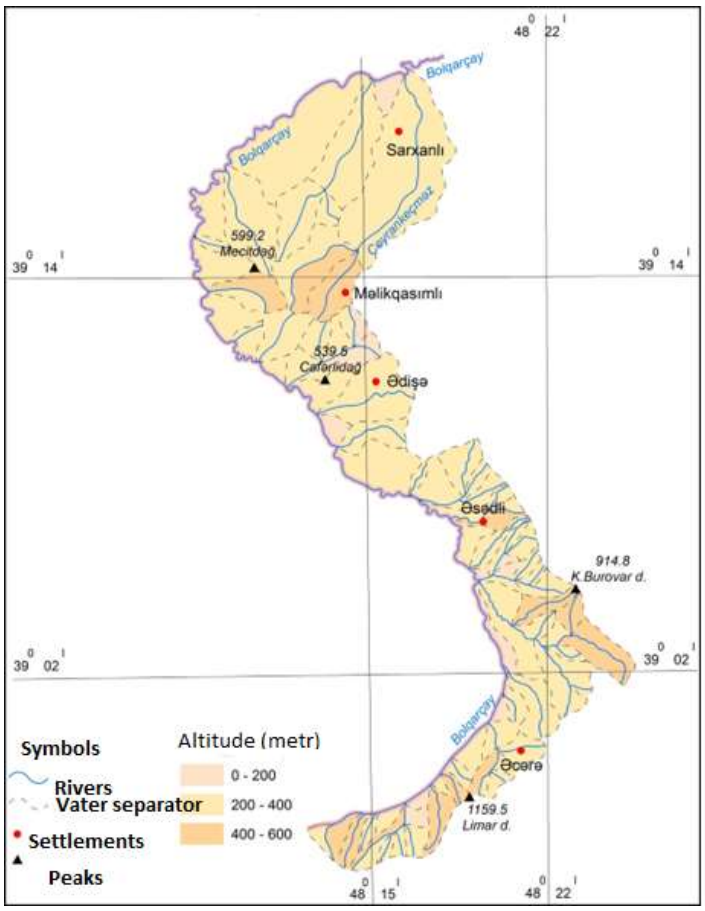

Figure 1: Deep Dissection Map of the Bolgarchay Basin (Fragment)

Based on the map, the morphometric indicators of the slopes' deep dissection were analyzed, and a table (Table 1) and a histogram (Figure 2) were created.

S/s	Slope height (metr)	Areas	
		Absolute value km^2	Percentage %
1	2	3	4
1	0-200	16,68	5,42
2	200-400	248,41	80,76
3	400-600	42,51	13,82
Total		307,60	100,00

Table 1: Quantitative Indicators of Deep Dissection of Slopes in the Bolgarchay Basin

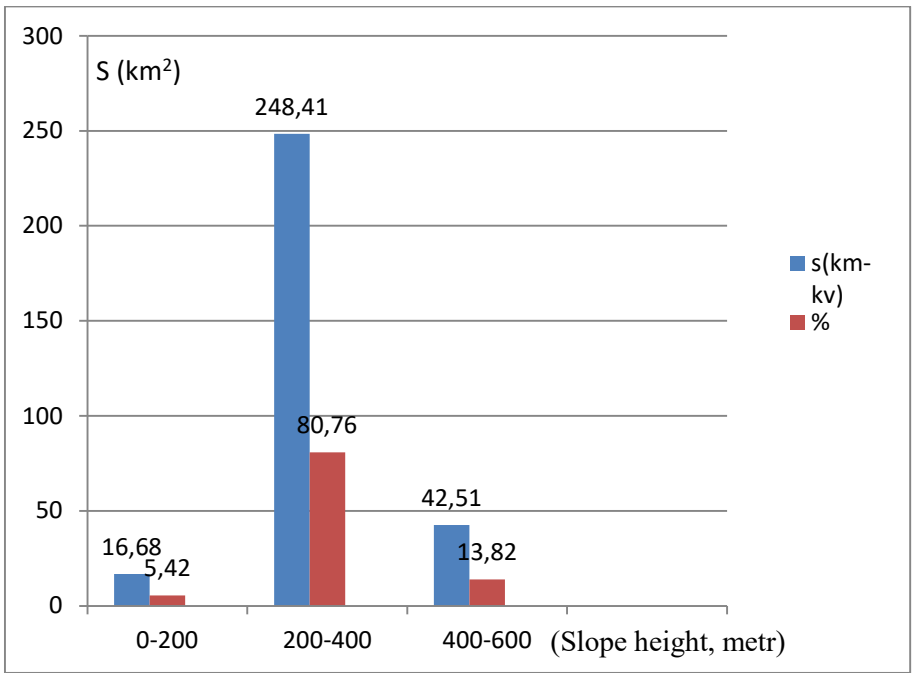

Figure 2: Histogram of Deep Dissection of Slopes in the Bolgarchay Basin.

The results of the morphometric analysis of the deep dissection of the Bolgarchay basin indicate that slopes with elevations between 200–400 meters predominate in the studied area, covering 248.41 km², which accounts for 80.76% of the delineated slopes. Generally, slopes with elevations between 200–600 meters dominate the Bolgarchay basin.

The analysis of the basin's deep dissection reveals that its upper reaches are rich in ravines and gullies, which are particularly widespread in the areas up to the Əsədli settlement.

Additionally, the results of the morphometric analysis of the slope aspects in the Bolgarchay basin can be included. Specifically, slopes with northern orientations (north, northeast, northwest) dominate, covering an area of 145.60 km² (42.02%) [6]. The relatively low average values and density of the morphometric indicators of the basin's deep dissection, particularly for north-facing slopes, indicate that the basin is significantly dissected.

It is also noteworthy that the studied area possesses significant recreational resources and aesthetic potential, making it a unique natural asset. This contributes to its importance for the development of ecotourism (geotourism) and the preservation of geomorphological natural monuments [7, 8].

These findings can be used in planning the placement of various agricultural crops by prioritizing suitable areas, taking into account the crops' heat and moisture requirements, and attracting tourists to the region. Furthermore, in the context of the recent nationwide expansion of construction and development, such data can be applied in the creation of various engineering structures, thereby increasing the significance of the obtained results.

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Pedagogical Sciences

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TEACHING METHODS OF ENGLISH IN SCHOOLS

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Abstract
The teaching of English as a foreign language in schools has undergone significant transformation over the past century. From grammar-translation practices rooted in classical education to communicative and technology-driven approaches, methods of instruction have reflected broader educational paradigms and societal needs. This paper reviews traditional, communicative, and innovative methods of teaching English in schools, highlighting their strengths, limitations, and implications for contemporary education. The study argues for a balanced approach that integrates the advantages of various methods, thereby ensuring both linguistic accuracy and communicative competence in learners.
Keywords: English teaching, grammar-translation, communicative approach, innovative methods, CLIL, language pedagogy

Introduction

The role of English in the modern world has expanded beyond national borders, making it the dominant language of business, science, technology, and global communication. Consequently, the demand for effective methods of teaching English in schools has increased dramatically. While English is a native language for some learners, for the majority it is taught as a foreign or second language within formal educational systems. The teaching of English in schools has never been static. It reflects changing theories of learning, evolving social needs, and the influence of new technologies. Understanding the strengths and weaknesses of different teaching methods allows educators to make informed decisions about their classroom practices. This article explores three broad categories of teaching methods: traditional, communicative, and innovative approaches.

Literature Review

Scholarly interest in language teaching methodology dates back to the late 19th century, when the grammar-translation method dominated instruction across Europe and Asia (Richards & Rodgers, 2014). Later, the audiolingual method, influenced by structural linguistics and behaviorism, became widely adopted, particularly in the mid-20th century. However, both approaches were criticized for their inability to produce fluent speakers capable of real communication. In the 1970s, the Communicative Language Teaching (CLT) approach emerged, focusing on meaningful interaction and functional language use (Littlewood, 1981). This method emphasized fluency, learner autonomy, and the practical use of language in real-life contexts. In recent decades, researchers have also advocated for innovative approaches such as task-based

learning, project-based learning, and Content and Language Integrated Learning (CLIL) (Coyle, Hood, & Marsh, 2010).

Overall, literature suggests that no single method is universally superior. Effective teaching requires the integration of multiple approaches tailored to learners' needs, cultural contexts, and institutional goals.

Traditional Methods

Grammar-Translation Method

The grammar-translation method is one of the oldest and most widely known methods. It is based on the study of grammar rules, vocabulary lists, and translation exercises between English and the learners' native language.

Strengths:

-Provides a strong foundation in grammar and vocabulary.

-Improves reading comprehension and writing accuracy.

-Familiar and straightforward for teachers to implement.

Weaknesses:

-Neglects speaking and listening skills.

-Encourages rote memorization rather than practical communication.

- Often considered monotonous and demotivating for students.

Audiolingual Method

Developed in the mid-20th century, the audiolingual method emphasized listening and speaking skills through repetition, drills, and memorization of dialogues.

Strengths:

-Helps improve pronunciation and listening comprehension.

- Provides structured practice in sentence patterns.

Weaknesses:

-Limited opportunity for creative language use.

- Overemphasis on mechanical repetition rather than meaningful communication.

Communicative Methods

Communicative Language Teaching (CLT)

CLT shifted the focus from grammar accuracy to communicative competence. Lessons are designed around real-life situations, role plays, discussions, and interactive tasks.

Strengths:

-Encourages active participation and student engagement.

-Builds confidence in speaking and listening.

- Develops skills needed for real-life communication.

Weaknesses:

-May lead to neglect of grammatical accuracy.

- Requires highly skilled teachers to balance fluency and correctness.

The Direct Method and Full Immersion

In these approaches, teachers use only English in the classroom, avoiding translation into the native language. Students are encouraged to think and respond in English.

Strengths:

-Creates an authentic language environment.

- Accelerates comprehension and fluency.

Weaknesses:

-Difficult for beginners with no prior exposure.

- Can cause frustration if not supported with visual aids and scaffolding.

Innovative Methods

Project-Based Learning (PBL)

Project-based learning integrates language skills with meaningful projects such as presentations, reports, or creative productions.

Benefits:

-Develops collaboration, creativity, and critical thinking.

- Encourages students to use English in authentic contexts.

Task-Based Learning (TBL)

This method organizes instruction around tasks that reflect real-life language use, such as ordering food, making travel arrangements, or conducting interviews.

Benefits:

-Promotes functional language skills.

- Increases student motivation through goal-oriented activities.

Content and Language Integrated Learning (CLIL)

CLIL involves teaching academic subjects, such as history or science, through the medium of English.

Benefits:

-Reinforces both subject knowledge and language acquisition.

- Prepares students for higher education and global opportunities.

Challenges:

- Requires well-trained teachers with dual expertise in subject matter and language pedagogy.

- Demands significant resources and curriculum adaptation.

Technology-Enhanced Learning

Digital tools such as online platforms, mobile apps, virtual classrooms, and gamification have revolutionized language teaching.

Benefits:

-Provides access to authentic materials and global communication.

-Encourages individualized learning and self-assessment.

- Increases motivation through interactive activities.

Discussion

The comparative analysis of different methods reveals that each has unique contributions to offer. Traditional methods provide grammatical accuracy and structure, communicative approaches foster fluency and confidence, and innovative techniques harness creativity and technology.

However, relying exclusively on one method is insufficient. A balanced, eclectic approach that combines grammar instruction with communicative practice and technology integration appears most effective for today's learners. Teachers must also consider age, proficiency level, cultural background, and learning styles when selecting methods.

Conclusion

Teaching English in schools requires a dynamic and flexible methodology. Traditional approaches remain useful for building foundational knowledge, while communicative and innovative methods respond to the needs of a globalized, digital society. Future directions in language education should focus on blended learning models, teacher professional development, and equitable access to technological resources. Ultimately, the most effective teaching strategy is one that adapts to learners' evolving needs and prepares them for successful communication in the 21st century.

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INNOVATIVE METHODS OF TEACHING ENGLISH IN COLLEGES AND UNIVERSITIES

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Abstract
The teaching of English in higher education institutions has experienced remarkable change in recent decades, shifting from teacher-centered approaches to learner-centered and technology-driven methodologies. Colleges and universities play a critical role in equipping students with advanced English proficiency for academic, professional, and global contexts. This article explores innovative methods of teaching English in higher education, including project-based learning, task-based learning, Content and Language Integrated Learning (CLIL), blended learning, gamification, the flipped classroom, and technology-enhanced approaches. The study highlights their benefits, challenges, and implications for modern pedagogy, ultimately suggesting a holistic framework that combines these innovations to maximize student engagement and learning outcomes.
Keywords: English teaching, higher education, innovative methods, blended learning, CLIL, gamification, flipped classroom, technology-enhanced learning

Introduction
English proficiency is considered a key competence for students in colleges and universities worldwide. In the era of globalization, higher education institutions are responsible not only for providing subject-specific knowledge but also for preparing graduates for intercultural communication, international collaboration, and professional competitiveness. Traditional methods, while still valuable, often fail to meet the dynamic needs of modern learners. Innovative teaching approaches have therefore become increasingly significant in higher education English pedagogy.
This article aims to investigate the innovative methodologies currently applied in teaching English in colleges and universities, emphasizing their effectiveness in enhancing language skills, learner motivation, and academic performance.

Literature Review
Research on language teaching methodology has demonstrated that innovation is not merely the replacement of old techniques with new ones, but rather the adaptation of teaching to evolving learner needs and societal demands (Richards & Rodgers, 2014). In higher education, the emphasis has shifted towards interactive and student-centered learning (Harmer, 2015).
Studies on project-based learning (PBL) highlight its role in fostering collaboration and real-world application (Thomas, 2000). Task-based learning (TBL) has been shown to improve communicative competence (Ellis, 2003). CLIL integrates subject learning with language acquisition, proving particularly effective in preparing students for international contexts (Coyle, Hood & Marsh, 2010). Meanwhile, blended learning combines face-to-face teaching with digital resources, offering flexibility and autonomy (Garrison & Vaughan, 2008).

Furthermore, innovative strategies such as gamification and the flipped classroom have demonstrated positive effects on student motivation and active participation (Bishop & Verleger, 2013). Collectively, the literature supports a paradigm shift towards multimodal and technology-driven pedagogies in higher education English teaching.

Innovative Methods in Higher Education

1. Project-Based Learning (PBL)

PBL engages students in extended projects requiring research, collaboration, and presentation in English. In universities, projects may involve writing academic papers, delivering multimedia presentations, or conducting cross-cultural studies.

Benefits:

-Enhances teamwork, critical thinking, and authentic use of English.

Challenges:

- Requires substantial planning, assessment criteria, and instructor guidance.

2. Task-Based Learning (TBL)

TBL organizes instruction around meaningful tasks such as debates, negotiations, or simulations of workplace scenarios.

Benefits:

-Promotes communicative competence and problem-solving.

Challenges:

- Assessment of task performance can be subjective.

3. Content and Language Integrated Learning (CLIL)

CLIL introduces English as the medium of instruction for academic subjects such as economics, medicine, or engineering.

Benefits:

-Dual focus on subject knowledge and language skills; prepares students for global careers.

Challenges:

- Demands bilingual instructors and specialized materials.

4. Blended Learning

Blended learning combines classroom teaching with online learning tools such as Moodle, Coursera, or Google Classroom.

Benefits:

-Flexibility, accessibility, and opportunities for autonomous learning.

Challenges:

- Requires digital literacy and institutional support.

5. Gamification

Gamification incorporates elements of gaming—points, badges, leaderboards—into English learning.

Benefits:

-Increases motivation, competitiveness, and student engagement.

Challenges:

- Risk of focusing on rewards rather than learning outcomes.

6. Flipped Classroom

In this model, students study theoretical materials (videos, readings) at home and engage in practice, discussions, and problem-solving during class.

Benefits:

-Encourages active learning and maximizes classroom interaction.

Challenges:

- Relies on student self-discipline and access to technology.

7. Technology-Enhanced Learning

Technology provides diverse resources such as mobile applications (Duolingo, Quizlet), online forums, AI-powered writing assistants, and virtual exchange programs.

Benefits:

-Exposure to authentic materials, intercultural communication, and individualized feedback.

Challenges:

- Digital divide, over-reliance on technology, and data privacy issues.

Discussion

The analysis of innovative methods reveals that higher education benefits most from a blended and flexible approach. While PBL and TBL provide authentic contexts for language use, CLIL fosters interdisciplinary competence. Gamification and flipped classrooms increase motivation and participation, while technology ensures access to global resources.

However, implementation challenges remain. Institutions require well-trained educators, adequate funding, and digital infrastructure. Pedagogical innovations must also align with academic standards and learning objectives. Ultimately, innovation in teaching English at the tertiary level should prioritize inclusivity, adaptability, and sustainability.

Conclusion

Innovative methods of teaching English in colleges and universities represent a significant advancement in higher education pedagogy. These approaches not only improve language proficiency but also cultivate transferable skills such as collaboration, creativity, and critical thinking. A combination of project-based learning, task-based learning, CLIL, blended learning, gamification, flipped classrooms, and technology-enhanced practices creates an effective and engaging framework for 21st-century learners.

Future directions should focus on integrating artificial intelligence, virtual reality, and global online collaborations into English instruction. Higher education institutions must continue investing in teacher training and digital infrastructure to ensure that innovation leads to meaningful and sustainable outcomes.

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ETHNOPEDAGOGY AS AN IMPORTANT FIELD OF PEDAGOGY

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Abstract. The article also attempts to define the basic concepts of ethnopedagogy. The article expresses an attitude towards the clarification of concepts such as “ethnos”, “ethnic knowledge”, “ethnic culture”, which are also the object of research of many other humanities. The article clarifies the concepts of “ethnopedagogical knowledge”, “ethnopedagogical culture”, and determines the mutual relationship between folk pedagogy and ethnopedagogy. Keywords: ethnos, ethnopedagogical culture, ethnopedagogical knowledge, folk pedagogy, ethnopedagogy. Globalization, which has emerged as one of the objective manifestations of human development, covers all areas of modern life. Globalization, which has deeply penetrated the social life of modern societies, can cause positive and negative changes in the lives of countries and peoples, depending on the level of cultural development.

Keywords: economic interests, folk pedagogy, scientific concepts ethnopedagogy, ethnopedagogical culture and etc.

The problems of socialization of ethnic consciousness, the formation of ethnic culture should be studied by ethnopedagogy, along with various social sciences, and, in our opinion, with a heavier special weight. Why do we claim that ethnopedagogical research plays a special role in solving these problems? Because all other related sciences examine ethnos, ethnic unity, ethnic culture, etc. from a scientific and theoretical point of view and present them as a fact. Ethnopedagogy, on the other hand, determines the importance, role and ways of applying these in the formation of the personality of people, especially the younger generation, in the modern era. The unique ethnic qualities of each ethnos also form the basis for the formation of a people and nation with original characteristics. Nationality is also a key factor in the sciences that study these characteristics. From this point of view, ethnopedagogy, which deals with the problems of studying ethnic characteristics, is also a national science; for example, Azerbaijani ethnopedagogy, Chuvash ethnopedagogy, Kazakh ethnopedagogy, etc. Since “ethnopedagogy” (mainly and more) arose from pedagogy, it studies the facts and phenomena studied by the science of pedagogy, but in a unique, specific aspect. It is known that the second part of the concept of “ethnopedagogy” - “pedagogy” - is the science that studies the pedagogical process. Therefore, the uniqueness of ethnopedagogy, the fact that it has different characteristics, is connected with the “ethno” part of this concept. (1, 23)

The partial loss of material and spiritual wealth as a result of conflicts on national grounds and inter-country local wars shows that the people as a whole have not properly mastered their national values, and have not considered the use of rich national and spiritual values created over many centuries to be the most important condition for their vital existence.

The analysis of the tasks set by the grandiose reforms carried out on the path of independent statehood clearly shows that such an attitude to national spiritual values can be explained by the underestimation of traditional national culture, folk pedagogy, and the possibilities of using them in the upbringing of modern youth by educators, educators, and society in general. Every nation that strives to preserve its national identity should think about preserving, preserving, and further developing its ethnic culture by adapting it to the modern era, and should try to find solutions. In

this matter, the socialization of the ethnic consciousness of the nation, the acquisition of ethnopedagogical culture, play a very important role.

Thus, the first concept that needs to be clarified is “ethnos”. Let us say from the beginning that it has not been possible to give a complete scientific explanation of what ethnos is, a very complex phenomenon, to this day. All sciences whose object of study is human society try to investigate the problem of ethnos, and at the same time each science gives priority to aspects specific to its subject. Our main goal in this article is to generalize the studies conducted on ethnos, its characteristics, and ethnic culture in terms of the problem under study. The first studies that approached the concepts of ethnos and ethnic unity from a theoretical perspective are the collection of articles by the Austrian sociologist E. Francis entitled “Ethnos and Demos” and the work of the Genevan professor Aldo Dami “Determination of Ethnic Unity”.

An interesting idea about ethnos belongs to L.N. Gumilyov. He views ethnos not as a social, but as a natural - geographical phenomenon. “Ethnos is a particular human collective that has a special internal structure and original stereotype of behavior and sets itself against other similar collectives (“we” and “others”)” (5, 285). The Russian philosopher Y.I. Semyonov has interesting ideas about ethnos and ethnic associations. Speaking about the signs of ethnos, he shows that for a long time the main signs of ethnos were considered to be a psychological basis manifested in linguistic unity, territorial unity, economic life unity and cultural unity.

Although the fact that the main sign of ethnos is language is justified in one sense (for example, members of the Russian ethnic community are the only ethnos that speaks Russian. As well as Turkish, Finnish, Japanese, etc. ethnos), on the other hand, this sign does not justify itself when applied to the English, Spaniards, Germans, French. There are numerous ethnos that speak each of these languages; for example, Spanish is spoken not only by Spaniards, but also by Mexicans, Cubans, and Argentines, who are completely different ethnos. Indeed, language becomes an important sign for the ethnos at that time, when it plays an important role in the formation and development of cultural unity.

In Azerbaijan, the problem of “ethnos” has been studied more in the context of ethnopolitical processes. Although the study of the problems of various ethnoses living in our country began mainly in the 50s of the 20th century, serious research in this area has a more scientific character after independence. Among the research scientists, R. Mehdiyev, A. Dashdemirov, V. Abdullayev, A. Taghiyev, M. Shukurov, H. Orujov, V. Habiboglu, I. Jafarzadeh, V. Arzumanli, S. Khalilov, I. Agayev and others have paid some attention to the explanation of the concept of “ethnos” in their studies on national policy, national relations and the development of ethnopolitical processes. For example, according to I. Agayev, “ethnos means the unity of people of the same ethnic origin, regardless of their territorial distribution.” (2, 18).

Nizami Jafarov calls the people a “super ethnos”: “Azerbaijanis as a people (super ethnos!) were formed as a result of complex ethnic processes lasting more than a thousand years in a rather “uneasy” geography of the world from a socio-political point of view” (3, p.5).

Ethnos is a special type of social grouping that emerged as a result of natural-historical development, regardless of the will of people. The characteristic feature of an ethnos is its durability; an ethnos is a group of people who can maintain their existence for many centuries. Each ethnos has its own internal unity and special features that distinguish it from others. The strength of unity within an ethnos depends on the characteristics of people’s ethnic self-awareness. These features manifest themselves in various areas of the lifestyle of members of the ethnos. Three stages of development of ethnos are discussed: subethnos (also called primary ethnos, and each member of the ethnos becomes a member of a separate subethnos), subsequent ethnos (subethnos moves to the background, a single literary language is created based on one of the dialects), and the last ethnos (elitist, urban culture is created, national culture is formed). At

this stage, all people become members of the ethnos directly, without entering subethnos and ethnic groups.

One of the important features of the ethnos is language, which is the main means of communication between its members. Another sign of the existence of the ethnos is cultural unity. This includes, first of all, material culture of a mass nature, such as places of residence, types of economy and equipment, clothing, types of food, and spiritual culture, such as customs, folk art, religion, etc. The cultural unity of the members of the ethnos is closely related to their psychological characteristics.

Ethnos is a social phenomenon accompanied by biological connection. In our opinion, the main features of the ethnos include language and cultural unity, awareness of ethnic origin, and unity of ethnic consciousness. Thus, in our opinion, historically formed stable associations of people with common characteristics in terms of language, culture, customs, psychological makeup, awareness of their ethnic origin, and common ethnic consciousness can be called ethnos. One of the concepts related to ethnos is the concept of "ethnic unity."

The convergence of cultures, the clash of economic interests, the emergence of difficulties in protecting national interests, the gradual disappearance of ethnic characteristics should be accepted as characteristic features of modern life. The gradual deepening of these factors creates a threat of the collapse of the original cultures of peoples and the destruction of ethnoses. Along with the above-mentioned aspects, globalization has caused a “shaking”, awakening, and revival of all nations, even ethnic cultures that are losing their vital existence. T.G. Stefanenko calls this phenomenon the “ethnic paradox of the modern era” and writes that “in individual individuals and entire nations, interest in their ancestral roots manifests itself in a variety of forms, from the restoration of past customs and traditions, the folklorization of professional culture, the search for the “mysterious national spirit” to the creation or restoration of their national statehood.” (4.)

Folk pedagogy combines three important ethnopedagogical concepts: “pedagogical culture of the people”; “main factors of folk education” and “ethnopedagogical materials”… The concept of “ethnopedagogical materials” means cultural samples created by the people in connection with different spheres of social life, having a deep pedagogical content and value” (1, 50-51). According to Z.A. Khusainov, ethnopedagogical knowledge is the knowledge reflected in fairy tales, legends, songs, riddles, proverbs, parables, lullabies, rhymes, etc., and used in the education and upbringing of children. Professor of Karakand State University Sh.A. Mukhtarova, speaking about ethnopedagogical knowledge, writes: “By ethnopedagogical knowledge, we understand the integrated knowledge about the characteristics of the ethnos’ pedagogical traditions, aimed at the formation of the national self-awareness of the personality, and in professional pedagogical education, also the ethnopedagogical competence (competence) of future teachers.

Speaking about ethnopedagogical knowledge, K.J. Kojakhmetova believes that ethnopedagogical knowledge performs three functions: - it serves to create ideas about reality and the general ethnic situation in the world; - this knowledge serves to determine the direction of a person’s practical and spiritual activity; - ethnopedagogical knowledge helps to understand and recognize the complex system of kinship relations, the essence of ethnosocial roles and the regulation of relations between subjects of the ethnos by these roles, as well as the generation to which one belongs.

The “ethnopedagogical culture” that arises from the organic connection of these two concepts should be understood approximately as follows: Ethnopedagogical culture is an indicator of the level of development of personal qualities and professional training that meet the requirements of pedagogical work and ensure its high efficiency in accordance with the national psychology, customs, ethnic identity and language unity of any ethnos.

A few words about the concepts of “ethnopedagogy” and “folk pedagogy”. Folk pedagogy, its subject, means, methods, and features have been widely discussed in the scientific and

pedagogical literature. In this article, we will try to briefly discuss the general and specific aspects and mutual relations of folk pedagogy and ethnopedagogy.

The fundamental work “Azerbaijani Pedagogical Studies” written by Professor Farrukh Rustamov, which has been evaluated as an event in the Azerbaijani pedagogical environment in recent times, has become a very valuable contribution to our science. The title of the work proves the national nature of the science to which it belongs. In our opinion, one of the values of this work is that it serves to understand the Azerbaijani pedagogical science as a complete system. In my opinion, Azerbaijani pedagogical studies consist of the unity of three sciences that have an independent subject of study, methods and laws: general pedagogy, history of pedagogy and ethnopedagogy.

As can be seen, researchers view the concept of ethnopedagogical knowledge as part of ethnocultural concepts, as knowledge reflecting the characteristics of pedagogical traditions, including the natural-climatic characteristics of the region, national-cultural and historical originality. G. Nezdemkovskaya calls knowledge about the natural, historical, cultural and social life of ethnos (and therefore humanity as a whole) ethnopedagogical knowledge. This idea can be justified when approaching the issue from the perspective of the first component of the concept of “ethnopedagogy”. That is, it is accepted that there are various types of knowledge about ethnos. However, this knowledge is formed by various sciences in accordance with their subjects.

One of the concepts that needs a detailed explanation in connection with ethnopedagogy is “ethnopedagogical culture”. For a serious analysis of this concept, it is necessary to understand what pedagogical culture is in general. Since the end of the 20th century and the beginning of the 21st century, numerous studies have been devoted to the study of such problems as pedagogical culture, the formation of the pedagogical culture of future teachers, the pedagogical culture of parents, the characteristics of pedagogical culture in the modern era, etc. It is also possible to find studies in this area in the Azerbaijani scientific pedagogical environment. The content and essence of pedagogical culture can be briefly presented as follows: “Pedagogical culture is essentially a high level of development of personal qualities and professional training that meets the requirements of the work of a teacher and educator and ensures its highest level of efficiency” (3, 147)

Researchers mainly talk about four levels of development of pedagogical culture: pre-professionalism, the initial level of professionalism; average level of professionalism; higher level of professionalism. In our opinion, the first and most important condition for mastering pedagogical culture at the higher professional level is to have “innate” pedagogical qualities.

That is, one can master general pedagogical culture by working on all structural units, receiving education, and learning, but if a person does not have an innate desire to teach and educate, or the germs of pedagogical enlightenment, he cannot master pedagogical culture at the higher professional level. In order to educate his students as highly moral personalities, this is the level of pedagogical culture that must be present. The content of pedagogical culture can include the following: - pedagogical inclinations and interests of the teacher-educator; - pedagogical abilities (these are also of two types: social-pedagogical abilities and special pedagogical abilities); - special pedagogical preparation; - pedagogical skill (pedagogical technique, pedagogical tact, creativity, methodological level, etc.) - personal pedagogical labor culture In order to present the concept of “ethnopedagogical culture” in more detail, attention should also be paid to what “ethnic culture” is. Ethnic culture is a system of values formed on the basis of the national psychology, customs and traditions, awareness of ethnic affiliation and language unity of any ethnos, ethnic unity and ethnic group.

That is, ethnopedagogy is one of the components of pedagogy as an independent science. Until recently, ethnopedagogical studies consisted of generalizing the experience of any individual people in the field of education and were descriptive in nature. Since comparative studies were

not conducted in the study of the pedagogical heritage of individual peoples, these studies were based on almost the same theory and methodology.

All this makes it undeniable that a comprehensive study of ethnopedagogical problems will have a positive impact on the development of modern pedagogical science, on the establishment of education on folk, national foundations. In our opinion, there is a great need for serious study of ethnopedagogical problems in the field of Azerbaijani pedagogical science.

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USE OF NEW METHODS IN TEACHING TECHNOLOGY

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Abstract. Technology education serves to prepare personnel who have acquired the technical knowledge and skills necessary for the country's economic development and meet the requirements of the labor market. The rapid development of innovative technologies increases the need for highly qualified labor in modern production areas. Teaching technology at the school level creates the initial foundation for meeting this need.

Technology lessons allow students not only to master existing knowledge, but also to put forward new ideas and find creative solutions to various problems. During project and practical work, students develop both creativity and critical thinking skills by preparing products in terms of design, engineering, aesthetics and functionality.

Since the subject of technology aims to master both theoretical and practical knowledge and skills, the application of innovative teaching methods is especially important here. This article examines the theoretical foundations of new teaching methods used in teaching technology, their practical application and advantages.

In modern times, the development of society is closely related to the widespread use of information and communication technologies (ICT). The education system has not been left out of this development, and the use of new teaching technologies in the pedagogical process has become one of the important conditions. In particular, the application of modern methods and tools in teaching technology subjects creates conditions for the emergence of students' creative potential, the development of practical knowledge and skills, and the formation of innovative thinking.

Keywords: technology, new teaching technology, method, tool, theoretical knowledge, practical knowledge, feedback, assessment criteria, etc.

In the 21st century, globalization, the rapid development of information and communication technologies and digitalization have created significant changes in education, as in all areas. These changes have affected the essence of the pedagogical process, teaching methods and forms, and teacher-student relations. The failure of traditional teaching methods to meet the requirements of the modern era, the failure to form creative and critical thinking, labor skills, and innovative activity habits in students, has necessitated the application of new approaches.

New teaching technologies mean modern pedagogical approaches, ICT-based tools, and interactive methods applied in the teaching process. They ensure that students not only acquire theoretical knowledge, but also participate in practical activities. These technologies include the following:

- ✓ ICT-based teaching technologies (multimedia, virtual laboratories, simulations, electronic textbooks);
- ✓ Project and problem-oriented learning;
- ✓ STEAM (Science, Technology, Engineering, Art, Mathematics) approach;
- ✓ Constructivist teaching methods;
- ✓ Feedback and assessment technologies (e-portfolio, online test systems).

Since technology subjects are practical in nature, the use of new learning technologies in this area is particularly relevant.

The use of interactive whiteboards and electronic resources makes the teaching process more visual and engaging.

Virtual laboratories and 3D modeling programs allow students to gain knowledge in simulated conditions instead of real equipment.

Project-based learning involves students in creative activities, develops their skills in independent work and teamwork.

The STEAM approach ensures the integration of technology lessons with other subjects and forms complex knowledge in students.

The advantages of new learning technologies are as follows:

- ✓ Makes the learning process student-oriented;
- ✓ Increases students' interest and motivation;
- ✓ Harmonizes practice and theory;
- ✓ Expands the possibilities of an individual approach;
- ✓ Develops students' 21st century skills - critical thinking, creativity, communication and cooperation.(1, p.18)

A number of difficulties may arise in the teaching process, which are as follows:

- ✓ Incomplete formation of the material and technical base;
- ✓ Inadequate teachers' skills in using new technologies;
- ✓ Textbook and methodological support still prevail in the traditional direction.

In the modern era, the main goal of the education system is not limited to providing theoretical knowledge, but also to form students' life skills, prepare them for future labor activity, and actively participate in the socio-economic development of society. In this regard, teaching technology is of particular importance. Technology not only provides students with labor skills, creativity, and practical skills, but also has a significant impact on their intellectual, emotional, and social development.

Technology teaching is carried out in an integrated manner with other subjects such as mathematics, physics, chemistry, and art. This allows students to apply their theoretical knowledge in practice and establish logical connections between knowledge. Thus, students can establish a relationship between real life and the course material.

Conducting group and team work in technology lessons develops cooperation, communication, responsibility, and leadership skills in students. At the same time, this subject plays an important role in choosing a profession and allows students to evaluate their interests and abilities.(2, p.45)

New teaching methods are based on the principles of constructivist pedagogy. According to this theory, the student is not a passive subject who receives knowledge from the teacher, but an active participant who applies it in his/her own activities and draws new conclusions (Piaget, Vygotsky). Modern pedagogical approaches are aimed at developing the learner's cognitive activity, cooperation skills, research and creativity.

Compared to traditional methods, innovative teaching methods are distinguished by the following advantages:

- ✓ Strengthens the student's cognitive interest;
- ✓ Based on experience and practical activity;
- ✓ Provides individualized and differentiated learning;
- ✓ Develops 21st century skills (critical thinking, problem solving, communication, cooperation, digital literacy).

This approach is based on solving real-life problems. In technology lessons, students are presented with problems encountered in production or everyday life, and ways to solve them are sought. For example, conducting research on topics such as “energy saving in the household”,

"organization of the use of environmentally friendly materials" increases both the technical knowledge and social responsibility of students. (3, p.36)

Project-based learning is one of the most commonly used methods in technology lessons. Students work individually or in groups on the preparation of a certain product (for example, simple mechanisms, decorative items, examples of robotics). This method develops skills such as cooperation, planning, responsibility, and creativity.

Interactive whiteboards, 3D modeling programs (AutoCAD, Tinkercad), virtual laboratories, and simulations are widely used in modern technology lessons. Digital resources provide visualization of abstract concepts and conduct experiments in a safe environment.

Experience from different countries shows that the application of innovative methods in technology lessons significantly increases student achievement. For example:

- In Finland, the project-based approach serves the development of engineering and design skills in schools;

- Robotics and programming are widely used in technology lessons in Singapore;

- In Azerbaijan, within the framework of the "STEAM education" project, technology is taught with new content, and engineering-oriented skills are instilled in students.

Studies show that in such lessons, students' interest in the lesson increases, their creative activity is stimulated, and their future professional choices are positively influenced.

The application of new learning technologies in teaching technology subjects plays an important role in improving the quality of education. Modern pedagogical approaches and ICT-based methods serve to develop creativity, independence and practical skills in students. However, for their effective application, professional development of teachers, enrichment of the methodological base and strengthening of material and technical support are necessary.

The application of new teaching methods in teaching technology is one of the main priorities of the modern education system. These methods:

- ✓ develop students' creative thinking and practical skills,
- ✓ create a basis for personnel training in accordance with the requirements of the labor market,
- ✓ ensure interdisciplinary integration,
- ✓ create conditions for the mastery of modern technologies. (4, p.61)

Suggestions:

- ✓ Technology teachers should be regularly involved in trainings on innovative teaching methods;
- ✓ Digital laboratories and technical resources should be expanded in schools;
- ✓ The share of STEAM-based lessons should be increased, project and problem-based learning should be systematized;
- ✓ International experience should be used to help students acquire globally competitive skills. (5, p.82)

In conclusion, we can say that teaching Technology is of great importance for both individual and social development in the modern education system. This subject develops students' creative, practical and social skills, creates a basis for training specialists in accordance with the requirements of the labor market, and also contributes to the country's scientific and technical progress. Therefore, teaching Technology should be expanded, its content should be adapted to modern requirements and enriched with innovative teaching methods.

Technology lessons allow students not only to master existing knowledge, but also to put forward new ideas and find creative solutions to various problems. During project and practical work, students develop both creativity and critical thinking skills by preparing products in terms of design, engineering, aesthetics and functionality.

Since the subject of technology aims to master both theoretical and practical knowledge and skills, the application of innovative teaching methods is particularly important here. This article examines the theoretical foundations of new teaching methods used in teaching technology, their practical application and advantages.

In modern times, the development of society is closely related to the widespread use of information and communication technologies (ICT). The education system has not been left out of this development, and the use of new teaching technologies in the pedagogical process has become one of the important conditions. The application of modern methods and tools, especially in teaching technology subjects, creates conditions for the emergence of students' creative potential, the development of practical knowledge and skills, and the formation of innovative thinking.

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Literature

MOTIFS OF THE FIGHT FOR WOMEN'S RIGHTS IN THE WORK OF JAFAR JABBARLI

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Abstract. The issue of women's freedom has always made people, societies, states, and religions think. In every era and in every formation, there has been a different approach to this issue. However, the problem has not been properly resolved even today. Therefore, the issue of women's freedom is still the subject of great research and studies.

J. Jabbarli, who worked for the progress of Azerbaijani culture and theater and wished for the active participation of Azerbaijani women on the theater stage, highly appreciated the role played by women in the history of art during the People's Republic in 1918-1920. Before the Republic - during the years of tsarist rule, old-fashioned people did not let women on the theater stage and did not look kindly on women who went to the theater.

In such an environment, only educated members of the "uprava" who sat with the "governors" and "glavas", wives and sisters of officials would go to the theater. A typical representative of these ladies, Firangiz, at the suggestion and insistence of her brother Aslan, gets educated and gets acquainted with Russian culture, and later learns the rules of behavior typical of "nobles" from her tutor Nadia.

Keywords: women's freedom, society, state, human rights, religious fanaticism, cultural backwardness, ignorance and ignorance, women's tragedy, etc.

In the first decades of the 20th century, one of the most serious people who raised the issue of women's freedom was the great writer - playwright, poet, prose writer, theater critic, film critic (his titles are as countless as his services) Jafar Jabbarli.

In the play "Ogtay Eloglu", which J. Jabbarli began writing in 1921 and completed in 1922, he reflected the tragedy of Firangiz, who was overwhelmed with the desire to live and create, but whose rights were trampled upon.

Innocent and shy, Firangiz has a romantic, somewhat incomprehensible, sentimental attitude towards life and people, born from her hazy visions. Firangiz, who fell in love with Ogtay, is within the framework of dry and strict moral rules, as noted by the prominent critic Yashar Garayev: "Under the influence of her brutal father, a fanatical slave of one-sided family customs and feudalism, and her brother, who is petty, formalistic, and cold by nature, the gentle and warm feelings in Firangiz's heart were stifled, and a duality emerged in her character. Although Firangiz insisted that she would endure the hardships and tortures of the poor life she would spend with Ogtay, she did not think that this was a sweet fantasy world created in the heart of a romantic-minded girl. Firangiz, who was deprived of the rights of humanity and femininity, and who determined the path of fate, not herself, but her father and brother, could not realize this in real life. It was precisely this kind of injustice that, under the influence of Aslan Bey's threats, Firangiz destroyed the world of beauty she had imagined in her imagination and renounced her love. Of course, she took this step to protect Ogtay from her brother's threats. Firangiz actually loved his ideals in his person, not Ogtay. confirms. If it were not so, an open-minded and educated girl would not have consciously refused the love letters she wrote to Ogtay at the insistence of her brother".

Y. Garayev also considers Ogtay guilty of Firangiz's destruction: "When Firangiz was first involved in the filth of a dirty environment, Ogtay did not save her. However, it was only then that she could have been saved. They married Firangiz, abused her spiritually and morally, and then abandoned her. Firangiz, who destroyed Ogtay through her own mistake, also destroyed herself".

"However, even though Firangiz was destroyed, she managed to get back on her feet," writes Yashar Garayev: "The past ten years have played a certain role in Firangiz's life, guiding her towards evolution. Firangiz, who allowed her beloved's brother to insult her, does not agree to her husband Danyar Bey's spiritual destruction ten years later. She switches sides with Ogtay, who is left alone on stage, and, showing great sacrifice, takes on the role of the first female swan of the Azerbaijani theater stage. The painful paths she has gone through have prepared her for an independent life. Firangiz, who says, "I can now control my own destiny," comes to Ogtay's aid. This was a big and serious step for Firangiz. She says, "There is an abyss behind me now, I cannot turn back, step back!" and moves forward boldly."

Firangiz, the first swallow, achieves the happiness she desires: "Oh, Ogtay, how I wish I could be your beloved and play the role of Amalia! They applauded me too. But my father! Even my brother would not agree. I love Amalia's death very much. A person being killed innocently by their lover!" As it seems, the playwright assigns this happiness - the audience's applause, to Firangiz's performance as Ogtay's lover in the role of Amalia. But how? Firangiz, dressed as Amalia, opens her true heart to Ogtay, dressed as Karl: "Ogtay, I love you. Let's go out and talk about everything." But can Firangiz love Ogtay? Alas! This is only possible on stage, while in life Firangiz is a slave not to her own desires, but to her brother's gold and position. The gold that had made her talk like a gramophone a moment earlier is still dominant. Altun is capable of turning everything into its opposite...(1, p.3)

Y. Garayev's comment on the death of Firangiz is also interesting: "Isn't Ogtay late for this purpose? The Aslanbeys have long since realized their desires on Firangiz. No one can deceive him anymore. On the contrary, perhaps he himself is now preparing to take revenge on those who destroyed him. Indeed, wasn't rushing onto the stage for the first time, in the name of customs and laws, a revenge against the Aslanbeys and Danyarbeys? At a time when Danyarbey cowardly wanted to ruin the play, Firangiz resolutely went over to the Ogtay front. At such a time, didn't Ogtay's destruction of Firangiz mean destroying his own dream that had come true? Isn't this helping the dozens of spiteful eyes that were staring at the first girl thrown onto the stage to laugh, and the customs and laws that were being trampled on to laugh and celebrate?" The critic is right in asking these questions. Indeed, Firangiz had already come a long way. She is no longer the wife of Danyar bey Galachikhanov, but an actress who looks at life from a different perspective.

Agreeing with Y. Garayev's ideas, we would like to add that Firangiz, who was educated, knowingly destroys her own happiness and joy by saying that she does not love Oktay and becomes the obedient slave of her brother Aslan bey. J. Jabbarli shows that after Danyar bey leaves Firangiz, he marries another rich woman. Thus, the writer focuses on this tragic life that women, both educated and illiterate, fall into. What worried the playwright was that thousands of women, like Firangiz, are made unhappy and resentful of life, a man buys her because of the rich wealth of her family, spends her inheritance on gambling, and leads a depraved lifestyle by spending her days in debauchery and entertainment. While Aslan Bey does not consider Oktay a poor actor to be a burden to his honor, zeal, and reputation, he accepts Danyar Bey's sister Firangiz's life, squandering her wealth as she pleases, divorcing her, and marrying a wealthy woman. Because he has the same level and worldview as Danyar Bey. In that worldview, a woman is not put in her place as a human being, her rights and entitlements are trampled upon, her pride is broken, and money is almost always the basis of all this. (2, p. 17)

In the play "Ogtay Eloglu", J. Jabbarli reflected the role played not only by men, but also by women in the development of Azerbaijani theater art. In those days, there were many actors who

were constantly ridiculed, persecuted, and even killed by ignorant people. In such circumstances, the appearance of a woman on stage was a great revolution in itself. This revolution took place thanks to the bravery and courage of Azerbaijani women who were threatened with death in their families.

It is possible to see that the struggle against those who enslave women and trample on women's rights occupies one of the central places in J. Jabbarli's work not only from his plays, but also from the stories he wrote in the 1920s and 1930s. In the stories "Gulzar", "Dilbar", and "Dilara", the women's problem and the female motif are in the foreground.

In the story "Gulzar", which he wrote in 1924, J. Jabbarli created a typical image of girls made unhappy by superstition. The writer, who named his stories after his heroes, attributed the disaster that befell Gulzar to her innocence and the savagery and perversion of the people of that time. Gulzar, who was the embodiment of high chastity and honor in the village, was forced to experience a terrible night of disaster - the night when her honor was violated. All of Gulzar's hopes and refuge were dashed, and Mansur, fearing the scorn of the people, chased her away. "Gulzar" focuses on the deception of faith, the misfortunes caused by orphanhood and deprivation for women. The story "Dilbar" tells the story of a father (Hasan the man) who gave his educated daughter to a lender because he could not repay the debt he had taken, the tragedy of that girl herself (Dilbar) and, of course, of society and the era as a whole. Although he stipulated that Dilbar should receive an education when he gave her away, poverty does not allow Hasan the man to defend this right of his daughter. Dilbar's lifestyle is the most vivid example of the hardships that Azerbaijani women endure: "Dilbar spent her days studying the pulpit and reciting Yasin on Thursday evenings and the Quran in the evenings. Washing clothes, preparing food, and similar tasks fell on Dilbar like a heavy burden, not allowing her to open her eyes. She had to go out in front of her husband, receive him with courtesy and formality, smile, and laugh. Otherwise, punches and kicks were inevitable and merciless. Dilbar was buried in a black grave while she was alive. Her best days were when she was beaten, cried in a corner, her eyes black, and she fell ill and did not approach her husband." (3, p.36)

Jafar Jabbarli named most of his stories after women. This is not by chance. Thus, the main theme of the writer's stories is women's freedom, bringing the Azerbaijani girl to the stage, preventing girls from dropping out of education, the bitter life of women, and women's helplessness.

The writer wanted to see Azerbaijani girls educated, free, able to make their own decisions and protect themselves, and for this, he showed women the ways to do this through his works. Jafar Jabbarli brought women who were oppressed, humiliated, and deprived of their rights in the family and society to his work. Sometimes he showed a way out of this situation, and sometimes he described the destruction of women who were oppressed and humiliated in this family and society. This description opened the eyes of dozens of women. He called them to struggle.

One of the most influential stories of Jafar Jabbarli dedicated to this topic is the story "Güler". Despite the small size and number of characters, the writer's story "Güler" is of great importance for Azerbaijani literature in terms of its subject and problematics. This work can contain very deep meanings. The author is able to bring the current miserable situation to life in front of the reader's eyes with the influence of the environment.

Jafar Jabbarli's story "Güler" is very valuable in terms of describing the violation of women's rights and entitlements. The writer wanted the female protagonist, Guler, to appear in front of the audience as an Azerbaijani girl and act as an actress. No matter how hard Jafar Jabbarli tried, Guler, the female character in the story "Güler", could not succeed in bringing Guler to the cinema stage as the first Azerbaijani girl. In this story, the writer showed the current situation of the female protagonist by describing Guler's desires and the oppression against her in a very detailed way.

Among Jafar Jabbarli's stories dedicated to the injustice of women and the humiliation of Azerbaijani girls in society, one of the most impressive is the story "Gulzar". Jafar Jabbarli's story "Gulzar" was able to bring the current miserable situation to life before the reader's eyes due to the influence of the environment. By describing the inner fears, sufferings, and difficulties of Gulzar, the writer's female protagonist, he makes Gulzar's situation and sufferings cry out to people.

Gulzar was orphaned since childhood, she had no one except her blind mother and poor brother Aslan. Since her mother was blind, Gulzar had done all the hard work in the house since childhood. She kept livestock and wove carpets and rugs.

Gulzar was one of Jafar Jabbarli's images of a suffering woman. The author saw such a society as the cause of the suffering, torment, and tears of poor girls from loneliness, and their permanent deprivation of happiness. In his story "Gulzar", Jafar Jabbarli conveyed the lives of victims of rape in society through literature.

Dilbar, the female protagonist of Jafar Jabbarli's story "Dilbar", was a girl who could not sit still for a minute, did not give peace, and aroused enthusiasm and vitality in the entire class with her roar. Dilbar's forced separation from school, education, classmates, and teachers and marriage became a tragedy for this young girl.

By describing the girl who had to bear such great troubles alone with her small body, unable to bear the troubles, experiencing nervous shocks, and crying all day, and by showing the bitter end of her life, the writer calls on parents not to separate their daughters from school and education at an early age. (4, p.72)

Dilbar was Jafar Jabbarli's female protagonist with great dreams. She wanted to study and become a doctor, wear a white dress and look after the sick, help her father, and raise her old father's head high. However, these dreams of poor, poor Dilbar were destroyed by society. Poor Dilbar was forced to agree to marry Mirza Karim in exchange for paying off her father's dead horse and a debt of six hundred manats. By describing Dilbar's life, Jafar Jabbarli showed that girls are still sold. The theme and problems of Jafar Jabbarli's story "Dilbar" are relevant for all times. The work was able to expose the environment in which women are condemned. Jafar Jabbarli created the image of a selfless woman with the image of Zuleykha in the story "Aslan and Farhad". Even after she became Asker's wife, she endured all the suffering for her brothers. Zuleykha was very hurt by her husband Asker. Asker shouted at her for every little word. He found himself a Russian girl and lived with her day and night. Zuleykha, the suffering female image of Jafar Jabbarli, endured so much suffering out of helplessness, hoping that after Farhad graduated and earned a living, it would not be difficult for an engineer brother to keep his sister. Another female character in Jafar Jabbarli's story "Aslan and Farhad" was Gulzar. She is depicted as a woman who betrays her husband. Knowing full well that betrayal is washed away with blood, Gulzar throws a glass of acid in the face of her husband Aslan and blinds him. In his story "Aslan and Farhad", Jafar Jabbarli created the loyal and devoted Zuleykha against the treacherous female character Gulzar. Since Gulzar is a treacherous woman as a character, she knows that her brother Ahmed is a mortal danger to her, so she sets a trap for Ahmed, who comes to Gulzar's house to kill her, and makes him kill the spy with the knife in his hand. The police catch Ahmed. With the incident of Ahmed being taken to prison, Gulzar and Farhad no longer fear anyone. Seeing that it was impossible to make a living, the loyal Zuleykha began to work as a maid in a house so that her brother Aslan and herself would not starve to death. Zuleykha kept her brother Aslan with a thousand and one pains. After Zuleykha fell ill, they could not bear to stay hungry at home for days and were forced to beg in shame. The loyal Zuleykha did not abandon her blind brother until her last breath.

The female character of the story called “Golden Statue” by Jafar Jabbarli was a fifteen-year-old girl named Jeyran, wrapped in a scarlet shawl, who went to the spring with girls her age, talked to them, laughed, and jumped around. The writer’s female hero, Jeyran, who did not accept the

love and affection of Muzaffar, who was crazy about Jeyran's love, married one of his relatives. Muzaffar had heard the news of Jeyran's marriage and had contracted tuberculosis. This love had devastated Muzaffar, made him completely resentful of life, and made his illness even worse. (5)

Like Muzaffar, Jeyran did not bring good fortune to Jeyran. After a short time, Jeyran, who became a widow, went to the spring to remember her innocent days and saw a sick man there, dressed as a beggar, offering himself to the sun. Jeyran, who regretted his mistakes, realized that he was responsible for Muzaffar's poor state, took Muzaffar's hands in his own and promised to be his life partner from now on. However, Muzaffar's life had come to an end, it was already too late.

The heroine of Jafar Jabbarli's story "Dilara" was Dilara, a smiling, peaceful, beautiful, pure, and lovely little schoolgirl. Dilara's only desire was to go to school and get an education. Bashir, who is a selfless father figure, does everything he can to make this wish of his daughter come true. However, the misfortune that befell Bashir does not allow this wish to come true.

The sharpness of the struggle against those who trample on women's rights, which occupies one of the central places in J. Jabbarli's work, is relevant for all times. J. Jabbarli is one of the most valuable writers in Azerbaijani literature in terms of describing the abyss into which Azerbaijani women fall and the dark environment in which they are surrounded.

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Agricultural Sciences

Horse Breeding in Kazakhstan: Current State, Challenges, and Prospects

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Annotation. The article discusses the development of horse breeding in Kazakhstan, highlighting its historical significance, current state, existing challenges, and future prospects. As a country where horse culture is deeply embedded in national identity, Kazakhstan maintains rich genetic resources and traditions of horse breeding. However, the industry faces serious issues, such as insufficient funding, genetic resource preservation, and limited technological modernization. Recent initiatives, including the establishment of research institutions, the adoption of innovative technologies, and the development of new breeding programs, demonstrate the potential for further growth. The study concludes that strengthening institutional support and enhancing international competitiveness are essential for sustainable development of horse breeding in Kazakhstan.

Keywords: horse breeding, Kazakh horses, genetic resources, innovation, export, sustainability

Introduction. Kazakhstan is widely recognized as the land of horses, where horse breeding has been not only an economic activity but also a key element of cultural heritage. Traditionally, horses have played a vital role in transport, food production, rituals, and daily life [1]. In modern times, horse breeding continues to be a sector of both agricultural and cultural significance. The roots of Kazakh horse breeding date back to nomadic civilizations. Horses were essential for survival in the vast steppe, serving as companions in migration, warfare, and pastoral activities [2]. Currently, more than 14 native horse breeds are officially registered in Kazakhstan. Among them, the Jabe type is particularly valued for its endurance, adaptation to harsh climates, and dual-purpose productivity (meat and milk) [1]. Other types, such as Adaev horses, are highly regarded for speed and racing qualities [3] (Table 1).

Table 1 - Main Kazakh horse breeds and their characteristics

№	Breed / Type	Primary use	Key features	Region of distribution
1	Jabe	Meat, milk	Strong, enduring, adapted to climate	Central and Western KZ
2	Adaev	Racing, sport	Light build, high speed	Mangystau region
3	Kushum	Universal	Large frame, suitable for harness	Aktobe, West KZ
4	Kazakh horse	Traditional use	Multipurpose, resistant to cold	Across Kazakhstan

Current State and Challenges. As of recent statistics, Kazakhstan's horse population has grown to approximately 4.3 million heads, making it one of the leading countries in horse numbers worldwide. However, the industry is still dominated by low-productivity breeds with limited market demand and weak export potential (Table 2).

Table 2 - Horse population dynamics in Kazakhstan (2015–2024)

№	Year	Number of horses (million heads)	Growth rate (%)	Notes
1	2015	2.2	–	Post-crisis period
2	2017	2.7	+8.5	Gradual recovery
3	2019	3.1	+6.3	Expansion of small farms
4	2021	3.6	+7.8	State support measures
5	2023	4.1	+6.9	Export potential rising
6	2024	4.3	+4.8	Peak numbers in modern history

Key Problems. Economic difficulties: horse breeding remains underfunded and lacks sufficient state and private investments. Genetic resource preservation: purebred local horses face risks of genetic erosion due to insufficient breeding programs. Technological backwardness: modern tools such as digital monitoring systems, genomic selection, and smart farm technologies are rarely used [4]. Low market demand: despite being traditional products, commercialization and export of horse meat and kumis remain underdeveloped [5] (Table 3).

Table 3 - Key challenges and solutions for horse breeding in Kazakhstan

№	Challenge	Current situation	Suggested solutions
1	Low productivity of local breeds	High share of traditional stock	Selective breeding, genetic programs
2	Weak commercialization	Poor meat/milk market integration	Branding, export promotion, value-added products
3	Genetic resource risks	Risk of erosion of purebred lines	Genetic banks, DNA-based monitoring
4	Technological lag	Limited smart-farm practices	Digitalization, AI monitoring, smart tracking

New Directions and Development Prospects. In 2024, Kazakhstan established the Institute of Horse Breeding and Feed Production, tasked with improving breeding quality, conducting scientific research, and boosting exports. Governmental initiatives also include plans to create a national Horse Breeding Institute, reflecting strategic importance at the state level.

Innovative Technologies. Introduction of «Smart Farms»: GPS trackers, automated feeding systems, and digital health monitoring.

Genetic studies using SNP analysis are being launched to better understand and preserve the genetic diversity of local breeds.

Selective breeding programs, such as the development of the «Mamyr-Aktobe» intra-breed type of the Kushum horse, are expanding.

Export and Global Opportunities. There is potential for Kazakhstan to promote horse meat, kumis, and cultural equine products to international markets. Tourism and equestrian sports could serve as additional sources of income and branding for Kazakh horses. Positioning horse culture as part of Kazakhstan's intangible heritage may help raise global awareness and demand [6].

Conclusion. Horse breeding in Kazakhstan remains a sector of both cultural and economic importance. While the industry faces structural and financial challenges, current institutional reforms and the integration of modern technologies provide significant opportunities. By preserving genetic resources, improving productivity, and promoting exports, Kazakhstan has the potential to become a global leader in horse breeding and equine culture.

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Economic Sciences

Eléments conduisant à la participation des PME aux marchés publics à Madagascar grâce à l'e-GP

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Abstract
The integration of e-GP into Madagascar's public procurement and contract execution system can be a strategic lever for increasing the participation of small and medium-sized enterprises (SMEs). This article analyzes the factors that lead to SME participation in public procurement in Madagascar through e-GP. The results show that simplifying access to information through e-GP can lower barriers related to information asymmetry, thereby strengthening SMEs' trust in the contracting authority. In addition, the dematerialization of procedures facilitates administrative processes and lowers certain costs, thus enabling a greater number of SMEs to bid. Training, awareness-raising, and technical assistance are crucial for strengthening the capacities of SMEs and improving their competitiveness. However, there are some constraints, such as the inadequate digital infrastructure of some SMEs and the lack of technological skills in some SMEs. The study concludes that the participation of SMEs in public procurement in Madagascar depends on a number of factors.
Keywords : SMEs, public procurement, e-GP, participation, Madagascar

Introduction

Les marchés publics jouent un rôle fondamental dans l'économie par exemple au niveau national et niveau régional. Ils jouent le rôle d'une part, d'effet multiplicateur parce que les dépenses publiques en biens, services et travaux entraînent des commandes en cascade auprès de fournisseurs et sous-traitants, générant de l'activité économique dans différents secteurs comme la construction, l'informatique et les services. D'autre part, de stabilisateur macroéconomique car en période de ralentissement, l'Etat peut ajuster les investissements publics pour soutenir la demande globale et limiter la récession.

Les marchés publics peuvent conduire à l'incitation de l'innovation car les appels d'offres peuvent contenir des critères de performance ou des clauses pour la recherche et le développement qui encourage les entreprises comme les PME à offrir des solutions nouvelles. Ils peuvent également être un effet de levier technologique parce que les marchés publics peuvent entrainer à l'adoption des nouvelles technologies émergentes par exemple les énergies renouvelables, la numérique et la santé.

Grâce aux marchés publics, les débouchés pour les PME peuvent augmenter par conséquent, de nouvel emploi peut-être crée qui sécurise ainsi les flux de revenus stables et favorisant leur croissance.

La procédure d'appel d'offres transparent et concurrentiel permet d'avoir le meilleur rapport qualité-prix pour les administrations qui baisse le gaspillage et garantie également l'utilisation efficiente des fonds publics. Concernant les normes de qualité, les cahiers des charges et des clauses contractuelles fixent des exigences de performance, de durabilité et de responsabilité sociale qui contribue à améliorer les standards de prestation.

Les marchés publics peuvent conduire à des objectifs d'emploi de publics éloignés du marché du travail par exemple les jeunes et les chômeurs de longue durée. Ils peuvent également des critères environnementaux comme les produits éco-labellisés, la réduction des émissions et la gestion des déchets favorisant la transition écologique et la diffusion des pratiques durables.
Les marchés publics constituent un levier stratégique de politique économique, sociale et environnementale. Ils permettent de stimuler l'innovation, de soutenir les PME, de renforcer la cohésion territoriale et de promouvoir le développement durable. Il faut noter que les marchés publics peuvent affecter la croissance économique d'un pays.
Cet article est divisé en trois (03) parties, premièrement, il y a la revue des approches théoriques, deuxièmement, la partie méthodologique et troisièmement, l'analyse comparative entre Madagascar et les autres pays.

1-Approches théoriques

1-1-Points de vue de quelques auteurs

Selon Bernard Hoekman et Bedri Tas dans « Procurement policy and SME participation in public purchasing » en 2020, l'amélioration de la qualité du cadre réglementaire des marchés publics augmente la participation des petites et moyennes entreprises (PME) et leurs d'avoir les contrats surtout quand les marchés publics sont divisés en lots de petite taille. Ils les ont prouvés grâce à l'analyse empiriques des données européennes entre 2016 et 2017 et la conclusion est que les règles de passation des marchés publics mieux alignés concernant les bonnes pratiques peut augmenter la participation des petites et moyennes entreprises (PME) et la fraction en lots. Ils recommandent l'amélioration de la qualité réglementaire, la simplification des procédures et le découpage en lots adaptés aux capacités des PME.
D'après Idah Mohungoo, Irwin Brown et Salah Kabanda dans « A Systematic Review of Implementation Challenges in Public E-Procurement » en 2020, l'e-GP peut aider les petites et moyennes entreprises (PME), mais sa mise en place peut rencontrer quelques défis par exemple technologiques, organisationnel et environnemental freinant l'accès et l'utilisation par les petites et moyennes entreprises (PME). Ils ont prouvé cela à partir des obstacles techniques comme l'interopérabilité et les signatures numériques, organisationnels comme la formation et la résistance au changement, et les contextuels par exemple le cadre réglementaire et les problèmes spécifiques aux petites et moyennes entreprises (PME). De ce fait, ils ont recommandé des actions coordonnées comme le renforcement des capacités à travers la formation, la réglementation claire sur les aspects numériques par exemple la validité de la signature et l'assistance technique et financière des PME.
D'après Teresa Fernandes et Vítor Vieira dans « Public e-procurement impacts in small-and medium-enterprises » en 2015, dans l'étude cas de Portugal, l'e-GP donne des bénéfices concrets comme la réduction des coûts de transaction et la transparence, mais il exige des investissements et entraine quelques obstacles pour les PME par exemple la signature électronique et les coûts d'adaptation. D'après leurs interviews avec les dirigeants des PME du secteur de construction, les bénéfices sont la réduction d'utilisation de papier, la traçabilité et l'accès à l'information, mais les coûts initiaux et la complexité technique et organisationnelle pouvant décourager certaines PME. Alors, ils recommandent l'harmonisation des plateformes, le support technique aux PME, la

validation juridiques des outils numériques par exemple les signatures et la communication claires concernant les procédures.

1-2-Modèle de Iacovou et al.

Iacovou, Benbasat, et Dexter (1995) ont pu développer un modèle pour expliquer l'adoption de l'EDI (Electronic Data Interchange) dans les petites organisations sur la base de la TDI (Théorie de la Diffusion et de l'Innovation). Leur modèle a trois groupes de variables à savoir, premièrement, les avantages perçus qui se réfèrent au niveau de reconnaissance des avantages relatifs que l'innovation peut donner à l'organisation. D'après les auteurs, ce facteur a été identifié comme parmi les facteurs les plus critiques pour l'adoption et le développement des technologies de l'information pour les petites entreprises. Deuxièmement, la préparation organisationnelle, elle est liée au contexte organisationnel, particulièrement à la disponibilité des ressources financières et technologiques de l'entreprise et troisièmement, la pression externe, elle se rapporte à l'environnement organisationnel et elle est prise en compte dans le modèle Technologie, Organisation, Environnement proposé par Tornatzky et Fleischer (1990).

1-3-Modèle UTAUT

Le modèle UTAUT (Unified Theory of Acceptance and Use of Technology) est un cadre théorique qui est utilisé pour la compréhension et la prédiction d'acceptation et d'utilisation des technologies de l'information. Il est fait par Venkatesh et al. en 2003, ils offrent un modèle plus robuste et explicatif.

Lorsqu'il est appliqué à l'e-GP, le modèle UTAUT permet de faire l'analyse des facteurs qui influencent l'intention et le comportement des utilisateurs par exemple les autorités contractantes et les soumissionnaires à utiliser l'e-GP.

1-4-Théorie des coûts de transaction

D'après cette théorie, les organisations choisissent le mode d'organisation qui permet de minimiser leurs coûts de transaction. En appliquant ce principe aux PME, Williamson pense que l'e-procurement permet de baisser les coûts de recherche et de soumission d'offres, mais selon lui cela peut accroître les coûts de mise en conformité par exemple les normes et l'authentification électronique. Il a également constaté que cela peut être un gain d'efficacité pour les PME qui sont bien équipées, mais constitue un risque d'exclusion pour les PME aux capacités techniques limitées.

2-Méthodologie

Pour obtenir les résultats de cette étude, la méthodologie utilisée nécessite des enquêtes auprès de quelques PME sur l'utilisation ou non d'e-GP et quelques acteurs qui ont de lien de près ou de loin à l'e-GP. Dans ce cas, il faut utiliser les outils d'analyse des données par exemple STATA et Microsoft Office Excel. Il est important de souligner que les PME enquêtées veulent rester anonyme qui constitue l'une des limites de cette étude.

La méthodologie utilisée à cette recherche permet de mettre en évidence la taille de l'échantillon, les procédures de collecte des données et la méthode pour analyser les données. Il est important de préciser que l'enquête a commencé en mars 2025 au niveau des PME à Madagascar.

Pour bien comprendre les éléments conduisant à la participation des PME aux marchés publics à Madagascar grâce à l'e-GP, il faut connaître la taille de l'échantillon, la procédure de collecte des données et la méthode d'analyse des données.

2-1-Taille de l'échantillon

L'échantillonnage a été effectué auprès de 161 entreprises, mais après le nettoyage des données, 159 d'entre elles a été retenu et qui a constitué la base des données pour faire cette étude. La base des données est composée deux (02) échantillons différents, le premier échantillon est constitué par 107 PME qui veulent participer aux marchés publics grâce à l'e-GP et le deuxième échantillon contient 52 PME qui ne veulent pas participer aux marchés publics.

Il s'agit de la population visée autrement dit l'effectif des petites et moyennes entreprises (PME) nécessaire pour bien mener la recherche. Dans ce cas, ce sont les petites et moyennes entreprises (PME) malagasy qui utilisent l'e-GP qu'elles ont déjà soumissionné ou non.

2-2-Processus de collecte des données

2-2-1-Stratégie d'échantillonnage

Il s'agit d'assurer la représentativité de l'échantillon par exemple les régions à Madagascar, les différents types des marchés publics et les entreprises qui ont déjà soumissionné ou n'ont jamais participés aux marchés publics.

2-2-2-Outils et sources

Concernant les outils et les sources des données utilisés pour cette étude, premièrement, il y a le questionnaire en ligne et deuxièmement l'appel téléphonique. Troisièmement, il y a l'extraction des données administratives à travers le site de l'Autorité de Régulation des Marchés Publics (ARMP) à Madagascar par exemple le nombre de soumission des entreprises, les types des marchés publics dans lesquels elles ont soumissionnées et la localisation des soumissionnaires des marchés publics. Quatrièmement, des entretiens semi-directifs aux autorités contractantes des marchés publics, quelques personnels de l'Autorité de Régulations des Marchés Publics (ARMP) et quelques entreprises.

2-2-3-Etapes opératoires

Premièrement, il faut faire l'échantillonnage à travers des petites et moyennes entreprises (PME) en tenant compte par exemple la région où elles se situent et leurs secteurs d'activité. Deuxièmement, il faut concevoir le questionnaire qui contient par exemple l'âge, le forme juridique, l'expérience en marchés publics, les capacités numériques comme les équipements et la connectivité, la perception d'e-GP comme l'utilisation, la transparence, les délais, les coûts et l'équité, l'accès au financement et au garantie, la capacité technique, les charges administratives et la formation sur l'e-GP reçue, la participation, le nombre de soumissions, le nombre des marchés publics gagnés et les motifs de non-participation des entreprises. Troisièmement, il faut faire le nettoyage des données par exemple la vérification des doublons et des données manquantes. Quatrièmement, l'archivage et l'éthique par exemple le consentement des entreprises enquêtées, l'anonymisation, le stockage sécurisé et les autorisations des institutionnelles concernées.

2-3-Méthode d'analyse des données

2-3-1-La régression logistique

La régression est souvent utilisée pour mettre en évidence la relation entre la variable expliquée et une ou plusieurs variables explicatives. Il faut noter que quand la variable expliquée est une variable qualitative, la régression logistique est le plus adapté par rapport à la régression linéaire classique en moindres carrés. Si la variable expliquée n'a que deux (02) modalités, la régression logistique binaire est la plus adaptée à utiliser. Par contre si elle a plus de deux (02) modalités et non ordonnées, l'idéale est d'utiliser la régression logistique polynomiale. Et si la variable expliquée a plus de deux (02) modalités et qu'à la fois elles sont ordonnées, d'après Adeline Gillet et al. en 2010, il faut utiliser la régression ordinale.

2-3-2-Intérêts de la régression logistique

La régression logistique permet de connaître la relation entre la variable expliquée et la variable explicative. Il s'agit d'un modèle qui permet de relier la variable expliquée à des variables explicatives. Elle est applicable lorsque la variable expliquée est qualitative. Souvent, en recherche, elle est de type binaire par exemple, efficacité ou inefficacité d'un programme. Il faut noter que les variables explicatives peuvent être qualitatives ou quantitatives.

2-3-3-Formule mathématique de la régression logistique

Dans la régression logistique, la variable expliquée ou la variable réponse suit la loi de Bernoulli de paramètre p qui est la probabilité moyenne pour que l'évènement se produise lorsque

l'expérience est répétée une fois par contre, elle suit la loi Binomiale (n,p) si l'expérience est répétée n fois par exemple la même dose de médicament injecté sur n poulet. Dans la présente étude, selon SANHARAWI et al. en 2013, le paramètre de probabilité p est une fonction de combinaison linéaire des variables explicatives.

La fonction la plus utilisée pour relier la probabilité p aux variables explicatives sont la fonction logistique appelé modèle « Logit » et la fonction de répartition de la loi normale standard est nommé modèle « Probit ».

Ci-après l'expression analytique :

$$log\frac{P(x)}{1-P(x)} = \beta_0 + \beta_1 x + \cdots + \beta_p x \qquad xp = x'\beta \qquad (1)$$

Ou encore Logit pβ(x) = x'β,

Logit désigne la fonction bijective et dérivable de]0,1[dans R : p → log (p/(1-p)), elle est appelée fonction de lien.

L'équation (1) peut s'écrire aussi comme ci-dessous :

$$p_B = P_B(Y = 1|X = x) = \frac{e^{\beta_0+\beta_1 x}}{1 + e^{\beta_0+\beta_1 x}}$$

Avec :

Y : Comportements des PME aux marchés publics à Madagascar grâce à l'e-GP

X : Formation des PME, maturité technologique des PME, sécurité des données des PME, chiffre d'affaires des PME, compétence des PME aux marchés publics et soumission des PME aux marchés publics

De ce fait, la fonction est :

$$\begin{aligned} log\frac{P(x)}{1-P(x)} = {} & \beta_0 + \beta_1 formation\ des\ PME + \beta_2 maturité\ technologique\ des\ PME \\ & + \beta_3 sécurité\ des\ données\ des\ PME + \beta_4 chiffre\ d'affaires\ des\ PME \\ & + \beta_5 compétence\ des\ PME\ aux\ marchés\ publics \\ & + \beta_6 soumission\ des\ PME\ aux\ marchés\ publics + \varepsilon \end{aligned}$$

$Avec\ \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6\ sont\ les\ paramètres$ à $estimer\ et\ \varepsilon\ l'erreur\ ou\ le\ résidu.$

2-3-4-Test de multi-colinéarité

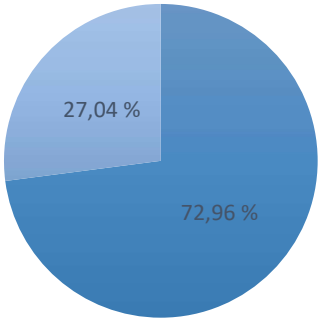
L'une des méthodes pour mesurer la colinéarité est l'observation des facteurs d'inflation de la variance (FIV). Ce dernier permet de connaître la multi-colinéarité. Il faut noter que la multi-colinéarité apparaît quand certaines variables de prévision mesurent le même phénomène. L'utilité des facteurs d'inflation de la variance (FIV) est d'estimer l'augmentation de la variance d'un coefficient en raison d'une relation linéaire avec d'autres prédicteurs. L'auteur Paul Allison affirme qu'il faut observer de près les variables qui ont un FIV supérieur à 2 ;5 et Erkel dit que c'est à partir de 5.

3-Etude de cas

3-1-Analyses descriptives

Sur 159 PME enquêtés pour comprendre les éléments déterminant la participation des PME aux marchés publics à Madagascar grâce à l'e-GP, ci-après le résultat de l'enquête.

Figure 1 : Résultat des enquêtes sur les PME



Source : Auteurs, 2025

La figure ci-dessus montre que sur les 159 PME retenues après l'enquêtes, 72,96 % des PME pense que l'e-GP affecte la participation des PME aux marchés publics à Madagascar par contre 27,04 % sont contre.

3-2-Résultat du test de multi-colinéarité

Tableau 1 : Facteur d'inflation de la variance (FIV) des variables explicatives

Variables	FIV
Formation des PME	1,34
Maturité technologique des PME	1,62
Sécurité des données des PME	1,69
Chiffre d'affaires des PME	1,30
Compétence des PME aux marchés publics	1,50
Soumission des PME aux marchés publics	1,14

Source : Auteurs, 2025

Le tableau ci-dessus montre que la valeur du FIV des variables explicatives sont en-dessous de 2,5 ce qui signifie que le risque de multi-colinéarité est quasi-nul d'après l'étude fait par Paul Allison.

3-3-Résultats d'estimation du modèle de régression

Tableau 2 : Relation entre la variable expliquée et les variables explicatives

Nombre d'observation = 159 LR chi2 (6) = 95,14 Prob > chi2 = 0,0000 Pseudo R2 = 0,4734		
Variables	Coefficient	P > | z |
Formation des PME	1,31**	0,01
Maturité technologique des PME	1,09**	0,04
Sécurité des données des PME	1,21**	0,03
Chiffre d'affaires des PME	1,30**	0,01
Compétence des PME aux marchés publics	1,11**	0,03
Soumission des PME aux marchés publics	1,13**	0,03
Constante	-3,35	0,00

Source : Auteurs, 2025

Ce tableau montre que la formation des PME (p-value = 0,01), la maturité technologique des PME (p-value = 0,04), la sécurité des données des PME (p-value = 0,03), le chiffre d'affaires des PME (p-value = 0,01), la compétence des PME aux marchés publics (p-value = 0,03) et la soumission des PME aux marchés publics (p-value = 0,03) sont significatif à la participation des PME aux marchés publics à Madagascar grâce à l'e-GP.

Sur 159 PME retenues sur cette étude, 27,04 % d'entre elles pense que l'e-GP n'a aucun effet à la participation des PME aux marchés publics à Madagascar parce qu'elles ont jugé que la formation des PME n'est pas assez, les données ne sont pas très sécurisées donc, certaines PME ont des faibles chiffres d'affaires, quelques PME ne sont compétentes concernant les marchés publics et que certaines PME n'ont jamais soumissionnés aux marchés publics. Mais, le pourcentage restant est contre ce qui est mentionné ci-dessus.

3-4-Analyse comparative

-Banque Mondiale (2016)

La Banque Mondiale considère que l'e-GP peut améliorer la transparence et l'équité d'accès aux marchés publics. La publication en ligne des appels d'offres peut aider les PME à accéder plus facilement aux opportunités, sans barrières liées à la distance et au manque d'information, et peut réduire la corruption. L'e-GP augmente la compétitivité et favorise la meilleure répartition des contrats publics.

-OCDE (2018)

Selon l'OECD dans son rapport en 2018 intitulé « SMEs in Public Procurement : Practices and Strategies for Shared Benefits », la digitalisation des marchés publics offre une opportunité pour démocratiser l'accès des petites et moyennes entreprises (PME) à celle-ci. C'est noté que l'absence d'accompagnement entraine continuellement à défavoriser les PME. D'après le rapport, qui est la synthèse des pratiques observées dans 37 pays, les obstacles récurrents sont la taille des lots, les exigences disproportionnées de capacité et des garanties, et la complexité administrative. Ainsi, dans ce rapport, les recommandations sont la simplification des documents, l'adaptation des exigences financières, le découpage des marchés, des portails e-procurement conviviaux, l'accompagnement et la formation des PME, et la partage de bonnes pratiques entre administrations.

-Commission Européenne (2020)

La Commission Européenne indique que l'e-GP favorise l'innovation et la compétitivité des petites et moyennes entreprises (PME) dans les marchés publics. La simplification et la standardisation des procédures des marchés publics grâce à l'e-GP encouragent la participation des petites et moyennes entreprises (PME). Auparavant, elles évitent les marchés publics jugés complexes. Cela permet de dynamiser la concurrence et de diversifier les fournisseurs.

Conclusion

La participation des petites et moyennes entreprises (PME) aux marchés publics à Madagascar peut connaître une évolution significative grâce à l'introduction d'e-GP. Cette innovation technologique constitue un levier essentiel pour améliorer la transparence, l'équité et l'efficacité dans les processus de passation et d'exécution des marchés publics. En facilitant l'accès à l'information, en simplifiant les démarches administratives et en baissant les coûts de participation, l'e-GP peut favoriser une inclusion plus large des PME qui sont souvent exclues par les procédures traditionnelles.

Plusieurs auteurs soulignent l'importance de ces facteurs. Neupane et al. (2014) affirment que l'e-GP augmente la transparence et diminue la corruption qui sont des conditions indispensables pour encourager la confiance des PME dans le système de passation et d'exécution des marchés publics. Vaidya et al. (2006) insistent sur la nécessité d'un environnement réglementaire qui est adapté et d'une formation adéquate des acteurs économiques pour maximiser les bénéfices d'e-GP. De même, Adebisi et Gbegi (2013) montrent que l'accès facilité à l'information et la simplification des procédures peuvent augmenter considérablement les chances de participation des PME. Enfin, l'OECD (2018) rappelle que la digitalisation des marchés publics est un catalyseur de développement pour les petites et moyennes entreprises (PME), en leurs ouvrant des nouvelles opportunités et en stimulant la concurrence.

En somme, l'e-GP est une opportunité stratégique pour intégrer davantage les PME dans les marchés publics à Madagascar. Toutefois, pour en exploiter pleinement, il faut faire un accompagnement pour cette transition numérique par des politiques publiques adaptées, la formation continue des acteurs, le renforcement des infrastructures numériques, la sécurité des données, la disponibilité des chiffres d'affaires nécessaire, la compétence et l'expérience en marchés publics. Ces conditions peuvent non seulement d'augmenter la participation des PME, mais aussi de contribuer au développement économique de Madagascar.

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Circular Economy, a New Paradigm for Sustainable Development

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Annotation

The circular economy is an innovative model that aims to rationally use resources, minimize waste, and ensure environmental sustainability [1]. The concept is an alternative to the traditional, linear economic model and is based on principles such as product reuse, recycling, and efficient resource management [2]. This article reviews the concept of the circular economy, its main principles, and its practical significance in the context of sustainable development.

The circular economy significantly contributes to environmental protection and the conservation of natural resources. Its implementation makes it possible to create new economic opportunities, including the development of innovative business models and the creation of new jobs. Following the example of the European Union, an additional 700,000 jobs were created in 2012-2018 within the framework of the Circular Economy Action Plan, which demonstrates the economic benefits of this approach. In Georgia, too, promoting the circular economy will help strengthen local production, reduce waste and improve environmental standards.

The implementation of a circular economy model for sustainable development requires active actions at both the political, business and societal levels. Companies are moving towards green production, where the emphasis is on the long-term use of resources, increasing the life cycle of products and compliance with environmental standards. Along with the development of a circular economy, investment opportunities are also increasing, which contributes to the introduction of new technologies and innovations.

In addition to economic benefits, the circular economy also provides important social and environmental benefits. For example, models operating within the framework of the circular economy contribute to reducing pollution, increasing energy efficiency and mitigating climate change. The introduction of sustainable production and consumption practices not only creates economic benefits, but also helps to raise public awareness, which is conducive to increasing environmental responsibility.

The potential for developing a circular economy in Georgia is significant. The country has the potential to develop waste management, energy sustainability and eco-friendly production. Examples of a green economy, such as the renewable energy sector, waste recycling and environmentally friendly transport systems, have already emerged and progress is being made towards the use of renewable resources. However, additional investments, stricter policies and more active public engagement are needed.

The circular economy is not just an environmental initiative, but a broad economic and social strategy for sustainable development that promotes innovation, the strengthening of new sectors, and the rational use of resources. Its implementation requires cooperation between both the public and private sectors to achieve ecological and economic stability in the long term.

Search words:Circular economy; Waste management; Design and Innovation'

Introduction

The modern world is facing sustainable development challenges related to the depletion of natural resources, climate change, increasing urbanization and uncontrolled arrears [Georgescu, M., & Popescu, C. (2019).]. The traditional, linear economic model ("take-use-throw") is no longer relevant to the scale of today's environmental and economic problems. In this context, the Circular Economy (CE) represents a new and promising approach that seeks to maximize the conservation, recycling and sustainable use of resources [Stahel, W. (2016).].

Circular economy involves not only reducing waste, but also a complete transformation of economic systems, which involves changing product design, rethinking production processes and adapting consumer behavior towards more ecological alternatives [United Nations Environment Programme. (2018).]. Its goal is to create a "closed loop" model, where resources retain their value and the negative impact on the natural environment is minimized [Ministry of Environment Protection and Agriculture of Georgia. (2022).].

The modern world is facing sustainable development challenges related to the depletion of natural resources, climate change, increasing urbanization and uncontrolled waste generation. The traditional, linear economic model ("take-use-throw") is no longer relevant to the scale of today's environmental and economic problems. In this context, the Circular Economy (CE) represents a new and promising approach that seeks to maximize the conservation, recycling and sustainable use of resources.

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Several important directives have been adopted in the European Union for the development of a circular economy, which define the obligations of producers, consumers, and state institutions towards sustainable production and consumption [European Commission. (2020).].

Main European directives:

1. EU Circular Economy Action Plan– A document adopted in 2020, aimed at better use of resources, reducing waste and developing green innovations [European Commission. (2020).].
2. Packaging and Packaging Waste Directive (Packaging and Packaging Waste Directive 94/62/EC)– obliges manufacturers to reduce packaging waste and increase recycling rates [Georgescu, M., & Popescu, C. (2019).].
3. Ecodesign Directive (Ecodesign Directive 2009/125/EC)– Regulates the design of products so that their environmental impact is minimized throughout their entire life cycle [Stahel, W. (2016).].
4. Waste Electronic Equipment (WEEE) Directive (2012/19/EU)– Requires manufacturers of electronic devices to recycle and safely dispose of their products [United Nations Environment Programme. (2018).].
5. Single-Use Plastics Directive (Single-Use Plastics Directive 2019/904)– Limits the use of single-use plastics and promotes the development of alternative, biodegradable materials [Ministry of Environmental Protection and Agriculture of Georgia. (2022).].

Georgia's Association Agreement with the European Union envisages the approximation of environmental regulations to European standards. In the direction of the circular economy, this implies:EPR-It is the development of the system, to ensure an effective waste management model [Ministry of Environment Protection and Agriculture of Georgia. (2022).]. Improving packaging and waste recycling, as defined by EU directives [United Nations Environment Programme. (2018).]. Introducing sustainable production and ecodesign standards, which will help local companies integrate into the EU market [Georgescu, M., & Popescu, C. (2019).]. Attracting investments in the

waste management sector, which will support the development of the local recycling industry [European Commission. (2020).].

For Georgia, the implementation of EU directives is an important step on the path to developing a circular economy. Their full implementation will contribute to both environmental protection and sustainable economic development.

Comparison of developed countries and Georgia in the context of circular economyThe implementation of the circular economy is taking place at different speeds and scales in developed countries and in Georgia.

European countries and the USA: The European Union is actively promoting the circular economy through regulations and strategic initiatives. For example, the EU Green Deal identifies the circular economy as one of its key areas. In the US, despite the lack of federal regulations, individual states (e.g. California) have implemented strong circular economy policies.

Asian countries: Japan, South Korea and China are making significant investments in recycling technologies, waste management and green manufacturing. For example, Japan has a "3R" (Reduce, Reuse, Recycle) policy, which is one of the most successful models globally.

Georgia: The development of a circular economy in Georgia is at an early stage. Although waste management strategies and environmental legislation are evolving in the country, challenges remain, such as insufficient recycling infrastructure, low public awareness, and lack of financial support for green initiatives. Georgia can benefit from the experience of the European Union and develop appropriate policies and practices for a circular economy.

The circular economy has significant benefits, including: Environmental protection and biodiversity conservation; New opportunities for economic growth and stimulation of innovation; Creating jobs in the green sector; Optimizing energy efficiency and material use.

Circular economy is an important element of modern economic policy, which ensures an environmentally sustainable and resource-efficient economy. Its successful implementation requires the active involvement of both state policy and the private sector and society. The effective implementation of this model can become an important driving force for sustainable development at the global level. It is important for Georgia to share international experience and adapt it to local needs, which will contribute to achieving sustainable development goals.

The circular economy is based on several key principles:

1. Efficient use of resources– Reduce, recycle and reuse at all stages of production and consumption.
2. Closed material flow– Minimizing waste and maximizing resource recovery.
3. Eco-design– Creating products and services in a way that reduces their environmental impact.
4. Bioeconomy and renewable energies– Regeneration of natural resources and use of alternative energy sources.
5. Systematic approach– Integrated involvement of all sectors of the economy and society in circular processes.

The value chain in a circular economy encompasses the entire process of creating, recycling, using, and disposing of a product or service, where resources are maximized and waste is minimized at each stage. Its key components include:

1. Resource extraction and production– Efficient use of raw materials, preference for renewable and recycled materials, introduction of eco-friendly technologies.
2. Design and innovation– Creating products that are durable, easy to repair, and reusable.
3. Consumerism and services– Development of new business models, such as product rental, sharing, and repair, which contribute to reducing consumption.
4. Waste management and recycling– Separation, recycling and giving a second life to used materials to reduce environmental impact.
5. Circular feedback– Avoiding waste and returning resources back to production, which creates a closed loop and increases resource efficiency.

The circular economy is successfully implemented in various sectors, such as:

- Green production: Companies like Patagonia and IKEA are trying to minimize waste and maximize the use of recycled materials.
- Waste management: Waste separation and recycling are widely used in European and Asian countries, which significantly reduces the impact on the environment.
- Energy: The integration of renewable energies (such as solar and wind energy) into the circular economy contributes to sustainable development.

Developed Countries And Georgia Comparative The analysis shows thatCircular Economy Implementation Developed In countries And In Georgia Different With speed And On a scale In progress.

Down Presented Comparative Analysis Table In the form of:

Parameter	Developed Countries(EU,USA,Japan)	Georgia
Strategy And Politics	Clear State Strategies,European Union"Green Agreement",Subsidies Green For businesses	Separate Legislation,But Clear Strategy Lack
Regulations And Standards	Strict Regulations And Waste Management Standards	Weak Regulations,Execution Low Level
Infrastructure	Developed Recycling Infrastructure,Sophisticated Waste Management	Recycling Insufficient Infrastructure
Financial Support	High Investments Circular In economics	Limited Financing And Investments Lack
Business Engagement	Private Sector Active Engagement,Green Initiatives	Green Businesses Low Level
Society Consciousness	High Consciousness And Engagement	Low Consciousness And Education Circular On the economy
Renewable Energies	Of the sun And Wind Energy Scalable Use	Slow Development And Small Investments

Europe Countries And USA:European Union Actively Develops Circular Economy Regulations And Strategic Initiatives by means of.For example,European Union"Green Agreement" (Green Deal)Circular Economy One-One Main Direction Names.USA-In,Despite Federal Regulations Lack of,Individual The states(For example.,California)Circular Economy Strong Politics Implemented.

Asia Countries:Japan,South Korea And China Important Investments They are laying Recycling In technologies,Waste Management And Green In production.For example,In Japan Valid"3R" (Reduce, Reuse, Recycle)Politics,which represents One-One Most Successful Model Global Level.

Georgia:Georgia Circular Economy Development Initial At the stage.Despite Of that,that In the country Waste Management Strategies And Environmental Legislation Developing,again There is Challenges,such as Recycling Insufficient Infrastructure,Low Public Consciousness And Financial Support Lack Green For initiatives.Georgia Can to take advantage of European Union With experience And To develop Circular Economy Relevant Politics And Practice.

The research analysis reveals thatThe economic impact of the circular economy is broad and includes the following components:

1. Employment growth– Creation of new jobs in green sectors, development of the processing industry.
2. Reducing company costs– Reducing raw material costs, using energy-efficient technologies.
3. Stimulating innovation– Development of new business models and technological solutions.
4. Attracting investments– Interest of international and local investors in green economy sectors.
5. Sustainable economic growth– Efficient use of resources, creation of new economic opportunities.
6. Reducing environmental costs– Reducing pollution, restoring ecosystems, and mitigating the negative effects of climate change.

Recycling is one of the key elements of a circular economy that ensures maximum use of resources and minimization of waste. Its goal is the secondary use of materials, which reduces the consumption of raw materials and at the same time reduces the harmful impact on the environment. In developed countries, recycling processes are strictly regulated, companies are obliged to reduce the waste generated and promote the recycling process. The recycling sector in Georgia is still at an early stage of development, although positive dynamics have been observed in recent years.

Basic stages of recycling

1. Waste collection– Creation of appropriate infrastructure and implementation of a waste separation system.
2. Sorting and recycling– Classification of waste according to its composition and use of appropriate recycling technologies.
3. Creating new products– Using recycled materials in the production of new products, which reduces the consumption of primary raw materials.
4. Market development– Promoting recycled products and encouraging green business models.

Economic and environmental benefits of recycling

1. Employment growth– The recycling industry creates new jobs, especially in the green economy.
2. Food saving– Recycling reduces the consumption of natural resources and promotes sustainable development.
3. Energy saving– The use of recycled materials significantly reduces energy consumption in the production of new products.
4. Waste reduction– Less waste means less pollution and a better environment for future generations.

Specific examples from EU countries:

- The Netherlands is known for its innovative recycling processes, such as the “Circular Valley” initiative, which brings together companies working to fully recycle waste.
- The "Returpack" system is successfully operating in Sweden, ensuring the recycling of almost 90% of plastic bottles and aluminum cans.

Georgian practice:

- The company "Neohub" in Tbilisi is actively working on plastic recycling, resulting in the creation of various new products.
- "Green Production" has an initiative that produces environmentally friendly packaging from recycled paper and cardboard.

- In 2022, a new waste separation center opened in Tbilisi, which contributes to an increase in recycling rates.

For Georgia, as a developing country, the development of the recycling sector is a necessary step towards creating an environmentally sustainable and economically profitable system. Cooperation between the state and the private sector is possible to effectively develop the recycling sector and fully implement the circular economy.

Green economy and circular economy are closely related concepts that share the common goal of sustainable development and reducing environmental damage [European Commission. (2020).]. Green economy refers to the establishment of an economic system that reduces negative environmental impacts, promotes the sustainable use of natural resources, and ensures environmentally sound growth [Georgescu, M., & Popescu, C. (2019).].

The circular economy, which can be considered a subsystem of the green economy, specifically focuses on the efficient use of resources and the minimization of waste [Stahel, W. (2016).]. Its core principles, such as recycling, resource recovery, and extending the life of products, are fully consistent with the goals of the green economy.

The relationship between the circular economy and the green economy:

1. Sustainable use of natural resources– The green economy and the circular economy jointly contribute to reducing the consumption of raw materials and the use of ecological alternatives [United Nations Environment Programme. (2018).].
2. Energy efficiency and renewable energies– Circular economy promotes the use of green energy, which reduces carbon emissions and increases sustainability [Ministry of Environment Protection and Agriculture of Georgia. (2022).].
3. Ecological innovations and technologies– Both models support innovative approaches that reduce environmental damage and increase resource efficiency [European Commission. (2020).].
4. Waste minimization and recycling– The main principle of the circular economy, waste reduction and recycling, is one of the fundamental components of the green economy [Georgescu, M., & Popescu, C. (2019).].
5. Socio-economic benefits– The green economy and circular economy create new jobs and promote sustainable production and consumption practices [Stahel, W. (2016).].

Thus, the green economy and the circular economy are closely linked and together represent the most important strategies for achieving sustainable development.

The green economy and the circular economy play an important role in creating new jobs and promoting sustainable production. These two concepts are closely linked and share the common goal of reducing environmental damage and using resources efficiently.

If we consider employment growth using the example of Europe,According to the EU Circular Economy Action Plan, the number of employees in sectors related to the circular economy increased by 5% between 2012 and 2018, which means an additional 700,000 jobs.

In Georgia Although specific statistical data on the impact of the green and circular economy on employment in Georgia is limited, the introduction of circular economy principles will contribute to the creation of new jobs. For example, the development of waste management and recycling sectors can become a new source of employment. Green and circular economies promote the introduction of environmentally friendly technologies and production processes, which reduce negative environmental impacts and increase resource efficiency. Implementing circular economy principles, such as recycling and resource recovery, reduces waste and promotes sustainable production.

In Georgia, the implementation of green economy principles is actively underway in various sectors. Some important examples are:

- **Energy efficiency and renewable energy**– A solar and wind power plant in Georgia, which was commissioned in 2016 and produces 20.7 MW of energy.
- **Waste management and recycling**– Waste recycling programs are being developed in Tbilisi and other large cities. The company "Neoprint" successfully produces recycled paper products.
- **Environmentally friendly transport**– Since 2020, Tbilisi's public transport fleet has been gradually replaced with Euro 6 standard buses, which significantly reduces emissions.
- **Organic farming and sustainable agriculture**– The number of organic farms that use natural fertilizers and sustainable farming methods is increasing in Georgia.

Thus, green and circular economy models will make a significant contribution to both employment growth and the development of sustainable production, which will ultimately contribute to the environmentally sustainable development of the economy.

The study identifies the circular economy in Georgia Strong And Weak Parties,Opportunities And Challenges

Strong Parties:

With the European Union Association Agreement,What Allow gives Europe Experience Sharing;
Natural Resources Wealth And Renewable Energy Potential;
Growing Interest Green Economy Towards;

Weak Parties:

Heterogeneous Politics And Insufficient Regulations;
Recycling Low Level And Infrastructure Lack;
Small Financial Resources Green For initiatives;

Opportunities:

European Union Financial And Technical Help;
Private Sector Turn on Green Business In development;
Circular Economy Education Integration;

Challenges:

Legislation Update Need;
Public Consciousness Increase;
Ecological Technology Implementation Tempo Acceleration.

Circular Economy represents Modern Economic Development Necessary Model.Developed With countries Comparatively,Georgia First More Needs Structural Reforms,However European Union With support And Correct By politics Possible Progress Achievement.State Politics,Private Sector And Society Joint With effort Possible Sustainable Economic Development Achievement And Circular Economy Principles Successful Implementation.

Georgia still needs structural reforms, but with the support of the European Union and the right policies, progress can be made. The joint efforts of state policy, the private sector and society have made possible Georgia's examples of circular economy.

1. **"Greentech" initiative**– Recycling plastic waste and producing environmentally friendly products.
2. **"Tene" – a second-hand clothing business**– Fabric recycling and recirculation of used clothing.
3. **"Zero Waste Georgia"**– Raising public awareness about waste management and recycling.
4. **"Solar Energy Georgia"**– Use of solar panels and renewable energy projects.
5. **"Caucasus Recycling"**– Recycling of glass and plastic for industrial materials.

Conclusion

Circular Economy Modern Economic Politics Important It is an element.,which Provides Ecologically Sustainable And Resource-Effective Economy.His/Her Successful Implementation Needs As State Politics,So Private Sector And Society Active Involvement.

The instrument,which Allow gives Economic Growth To happen Natural Resources Excessive Consumption Without.His/Her Basic Principles,such as Recycling,Waste Reduction And Resources Effective Use,Important Role Completes Environment Protection And Economic Stability In providing.

Developed With countries Comparatively,Georgia First More Needs Structural Reforms,However European Union With support And Correct By politics Possible Progress Achievement.

For Georgia It is important. International Experience Sharing And His/Her Adaptation Local Needs Considering,What Hand Will help Sustainable Development Goals It represents an achievement. Modern Economic Development Necessary Model.

Europe For example,Circular Economy Politics Implementation Reduced Waste Generate,Increased Energy efficiency And Create New Work Places.In Georgia too,This Model Implementation Requires Politics And Legislation development,Business Engagement To increase And Society Consciousness To rise.Green With the economy His/Her Tight Connection Provides Sustainable Development Goals achievement And Economic Benefit Maximize.

Finally,Circular Economy Implementation No is Only Environmental Initiative,But Strategic Economic Model,which Provides As Ecological,So Social And Economic Sustainability.His/Her Successfully Implementation Requires As Private,So Public Sector jointly Effort,In order to To be created Such Economic System,which Balancedly Will use Natural Resources And Hand Will help Future For generations Better Environment to create.

Circular Economy Principles Implementation And Society Ecological Consciousness Ascension The basis is,RelevantEducation. For this It is important. To be implemented:Circular Economy Integration Educational In programs; Business And Universities Cooperation Deepening Green Innovations In the direction; Society Consciousness Ascension Ecological And Economic Sustainability On issues; Practical Trainings And Workshops Future For generations.

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ROLE DE LA REGLEMENTATION CONTRAIGNANTE DANS L'INTEGRATION DES CONSIDERATIONS ENVIRONNEMENTALES DANS LES MARCHES PUBLICS DE TRAVAUX A MADAGASCAR

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RESUME

Les marchés publics de travaux représentent un levier essentiel de développement à Madagascar, mais ils peuvent générer des impacts environnementaux importants en l'absence de mécanismes de régulation adaptés. À partir d'une analyse économétrique (logit et probit) menée sur 94 dossiers d'appel d'offres ouverts (DAOO) lancés entre 2021 et 2023 par quatre ministères techniques, cette étude met en évidence le rôle déterminant d'une réglementation contraignante dans l'intégration des considérations environnementales. Les résultats montrent que l'intégration de clauses environnementales est fortement conditionnée par l'existence d'obligations juridiques explicites, alors que d'autres facteurs, tels que la taille financière des projets, exercent une influence secondaire. Toutefois, l'absence d'articulation entre la législation environnementale qui impose notamment des études d'impact, et la réglementation des marchés publics limite la portée et l'effectivité de ces obligations. L'étude souligne la nécessité d'un cadre juridique clair et contraignant, complété par des outils opérationnels, des capacités renforcés et un suivi rigoureux. Elle ouvre ainsi la réflexion sur les moyens d'articuler plus efficacement la législation environnementale et celle des marchés publics afin de soutenir la transition écologique à Madagascar.
Mots clés : Marchés publics, Travaux, Clauses, Réglementation, Environnement.

ROLE OF BINDING REGULATIONS IN THE INTEGRATION OF ENVIRONMENTAL CONSIDERATIONS IN PUBLIC PROCUREMENT OF WORKS IN MADAGASCAR

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ABSTRACT

Public procurement of works represents a key development lever in Madagascar, but it can generate significant environmental impacts in the absence of appropriate regulatory mechanisms. Based on an econometric analysis (logit and probit) of 94 open calls for tenders (DAOO) launched between 2021 and 2023 by four technical ministries, this study highlights the crucial role of binding regulations in the integration of environmental considerations. The results show that the inclusion of environmental clauses is strongly conditioned by the existence of explicit legal obligations, whereas other factors, such as project financial size, have a limited influence. However, the lack of coordination between environmental legislation, which notably mandates impact assessments, and public procurement regulations limits the scope and effectiveness of these obligations. The study emphasizes the need for a clear and binding legal framework, complemented by operational tools, strengthened capacities, and rigorous monitoring. It also opens the discussion on how to more effectively align environmental legislation with public procurement regulations to support ecological transition in Madagascar.

Keywords: Public procurement, Works, Clauses, Regulation, Environment.

1. INTRODUCTION

Les marchés publics de travaux représentent un enjeu économique très important. A côté des autres types de marchés (marchés de fournitures et services et marchés de prestations intellectuelles), ils mobilisent d'importants fonds publics pour la réalisation de grands travaux. À Madagascar, les marchés de travaux représentent, en termes de montant, plus de 60% des marchés soumis au contrôle a priori de l'organe de contrôle des marchés durant la période 2020 à 2022 (CNM, 2024). Cette prépondérance des marchés de travaux s'explique notamment par le poids que représentent les infrastructures publiques dans tout processus de développement économique. En effet, les investissements dans des projets d'infrastructures, comme des infrastructures de transport (routes, ponts, voies ferrées, aménagements portuaires et aéroportuaires…), des infrastructures hydroagricoles (barrages, périmètres irrigués…), et des infrastructures hospitalières et écolières sont essentiels pour la croissance économique du pays et le bien-être de la société.

Cependant, la construction ou l'entretien de ces infrastructures peuvent avoir des effets néfastes pour l'environnement. En 2011, le secteur de la construction est responsable, dans le monde de « 50 % du total des ressources naturelles exploitées, 45 % de la consommation totale d'énergie, 40 % des déchets produits, de 30 % des émissions de gaz à effet de serre et de 16 % de la consommation totale en eau » (Trachte, 2012). Ainsi, les marchés publics de travaux peuvent avoir des impacts importants sur l'environnement, s'ils ne sont pas réalisés de manière durable. L'enjeu environnemental des marchés publics de travaux est donc particulièrement crucial. L'intégration de considérations environnementales dans les dossiers d'appel d'offres (DAO) permet non seulement de limiter ces impacts, mais également de promouvoir l'adoption de pratiques de construction plus respectueuses de l'environnement, en cohérence avec les engagements internationaux en matière de lutte contre le changement climatique. Une telle intégration peut se

concevoir à quatre stades différents de la procédure des marchés publics : lors de la définition de l'objet du marché et des spécifications techniques, lors de la sélection qualitative de l'entreprise (critère de qualification), lors du choix de l'offre la plus avantageuse (critère d'attribution) ou lors de l'exécution du marché (conditions d'exécution) (Dugaillez et Martens, 2006 ; Melsen et Kuegelgen, 2012; Van den Abeele, 2014).

Bien que le Code des Marchés Publics (CMP) de 2017 a prévu la possibilité l'intégrer des clauses[15] et critères[16] environnementaux dans les marchés publics à Madagascar, cette possibilité est rarement utilisée par les acheteurs publics et le niveau d'intégration des considérations environnementales dans les marchés publics de travaux demeure faible (RAKOTOMANGA et al., 2024).

En effet, les dispositions du CMP relatives à l'intégration des considérations environnementales dans les marchés publics sont des mesures incitatives, et ne constituent en aucun cas des obligations. Les obligations environnementales dans le cadre des marchés publics de travaux à Madagascar concernent particulièrement les marchés publics portant sur des projets listés dans le Décret MECIE qui sont soumis à une Étude d'Impact Environnemental et Social ainsi que les marchés sur financement des bailleurs de fonds qui disposent des directives spécifiques en matière de sauvegarde de l'environnement. Ces obligations constituent ainsi une réglementation contraignante à laquelle les maîtres d'ouvrage et les entrepreneurs doivent se conformer.

Face à ce constat, l'on s'interroge : l'intégration des considérations environnementales dans les marchés publics de travaux à Madagascar dépend-elle avant tout de l'existence d'une réglementation contraignante ? L'hypothèse avance que l'intégration actuelle des considérations environnementales dans les marchés publics de travaux est fortement conditionné par l'existence d'une réglementation contraignante. L'objectif de cet article est donc d'évaluer empiriquement, à travers une modélisation économétrique (logit /probit), le rôle de la réglementation contraignante dans l'intégration des clauses environnementales dans les marchés publics de travaux à Madagascar.

2. MATERIELS ET METHODES

Pour vérifier empiriquement si l'existence de réglementation contraignante constitue le facteur déterminant de l'intégration des considérations environnementales dans les marchés publics de travaux, il convient de recourir à des méthodes adaptées à l'analyse d'une variable dépendante binaire, en l'occurrence la présence ou l'absence de clauses environnementales dans les dossiers d'appel d'offres.

À cet effet, les modèles de régression logit et probit apparaissent particulièrement appropriés. Ces modèles permettent en effet d'estimer la probabilité d'occurrence d'un événement à partir de variables explicatives, tout en garantissant que les probabilités estimées demeurent comprises entre 0 et 1. Le modèle logit repose sur une fonction de répartition logistique, tandis que le modèle probit utilise la fonction de répartition de la loi normale. Bien que reposant sur des formulations mathématiques distinctes, leurs résultats sont généralement proches et complémentaires (Hurlin, 2003). L'interprétation des coefficients estimés s'effectue à travers leur significativité statistique, les odds ratios dans le cas du modèle logit, ou encore les effets marginaux dans le cas du modèle probit, traduisant la variation de la probabilité d'intégration des considérations environnementales associée à une variation d'une variable explicative donnée.

a) Constitution de la base de données

[15] « Une ´ clause environnementale ou sociale est une exigence insérée dans le cahier des charges, en tant que spécification technique, et constitue une obligation pour les candidats aux marchés publics » (Thierno GUYE (2023). Guide d'achat public durable. Page 20.)

[16] Un critère environnemental est un critère utilisé pour la sélection ou qualification des candidats. Thierno GUYE (2023). Op.cit

La base de données de l'étude a été construite à partir de 94 Dossiers d'Appel d'Offres Ouvert (DAOO) de marchés publics de travaux lancés au cours des exercices 2021 à 2023 par quatre (04) ministères techniques sélectionnés, et dont les montants estimatifs atteignent les seuils de contrôle a priori de la Commission Nationale des Marchés.

Le Ministère des Travaux Publics (MTP) en charge des infrastructures routières, le Ministère des Transports et de la Météorologie (MTM) en charge des infrastructures aéroportuaires, ferroviaires, portuaires et logistiques, le Ministère de l'Agriculture et de l'Élevage (MINAE) en charge des infrastructures hydro-agricoles, et le Ministère de la Santé Publique (MINSAN) en charge des infrastructures hospitalières ont été retenus pour leur représentativité sectorielle et leur poids dans les investissements publics en infrastructures. Le choix de ces quatre ministères permet en effet de couvrir un éventail représentatif des secteurs d'infrastructures stratégiques à Madagascar aux impacts environnementaux variés., tout en offrant une diversité de types de travaux et de sources de financement.

À partir de cette base empirique, les variables retenues pour la modélisation ont été définies comme suit :

- Variable dépendante (Y) : présence d'une clause environnementale dans le DAO (1 = oui, 0 = non).
- Variable explicative principale : REGL_CONTR : existence d'une réglementation contraignante imposant l'intégration de clauses environnementales (1 = oui, 0 = non).
- Variable explicative complémentaire :

MONTANT : montant estimatif du marché (variable continue).

b) Étapes de la modélisation

Les étapes de la modélisation, détaillées ci-après, assurent une démarche cohérente et robuste pour identifier les déterminants significatifs et mesurer le rôle de la réglementation dans l'intégration des considérations environnementales.

Définition du modèle latent

L'approche Logit et Probit repose sur l'existence d'une variable latente non observée $Y*$, qui reflète dans notre cas d'étude la propension d'un marché public de travaux à intégrer des considérations environnementales.

Cette variable est définie comme suit :

$$Y^* = \mathbf{X}\beta + \varepsilon,$$

où :

- X est un vecteur de variables explicatives,
- β est un vecteur de coefficients à estimer,
- ε est un terme d'erreur aléatoire.

On observe Y = 1 si Y∗ > 0, et Y = 0 sinon.

$$Y = \begin{cases} 1 & \text{si } Y^* > 0 \\ 0 & \text{sinon} \end{cases}$$

Fonction de probabilité

La probabilité d'intégration environnementale (Y=1) conditionnellement aux variables explicatives X est donnée par :

$$\Pr(Y = 1 \mid \mathbf{X}) = F(\mathbf{X}\beta),$$

où F(·) est une fonction de répartition cumulative

Formulation des modèles

En fonction du choix de la fonction de répartition, les modèles prennent la forme :

$$\Pr(Y = 1 \mid \mathbf{X}) = \frac{1}{1 + \exp(-\mathbf{X}\beta)}$$

- Modèle Logit :

- Modèle Probit :

où Φ est la fonction de répa $\Pr(Y = 1 \mid \mathbf{X}) = \Phi(\mathbf{X}\beta)$ dard.

Estimation et évaluation de la qualité des modèles

Les paramètres β sont estimés par la méthode du Maximum de Vraisemblance (MV), qui consiste à maximiser la probabilité jointe d'observer les données de l'échantillon. coefficients ont été estimés par maximum de vraisemblance. La qualité des modèles a été évaluée à l'aide de plusieurs indicateurs : la log-vraisemblance (niveau d'ajustement global), le test du rapport de vraisemblance ($G2$) pour juger de la significativité conjointe des variables, et différents pseudo-R2 (McFadden, Cragg & Uhler/Nagelkerke) pour apprécier la qualité d'ajustement.

Interprétation des coefficients et effets marginaux

Les coefficients β indiquent l'effet directionnel des variables explicatives. Leur interprétation directe est plus intuitive via :

- les odds ratios dans le modèle logit : exp(βj),
- ou les effets marginaux : $\frac{\partial \Pr(Y = 1)}{\partial X_j}$.

Un coefficient positif signifi . le augmente la probabilité d'intégration ($Pr(Y$=1)). Un coefficient négatif indique qu'elle la réduit.

Effets marginaux : Pour une interprétation intuitive, on calcule les effets marginaux qui mesurent l'impact d'une variation unitaire d'une variable explicative (ou le passage d'une modalité à une autre) sur la probabilité d'intégration environnementale, toutes choses égales par ailleurs.

Les estimations ont été effectuées au moyen du logiciel R Studio, qui propose des outils adaptés à l'estimation des modèles logit et probit ainsi qu'au calcul des effets marginaux.

3. RESULATS

Les résultats de la modélisation économétrique (logit et probit) sont présentés en deux temps : d'abord l'estimation des coefficients des modèles logit et probit permettant d'évaluer l'influence de la réglementation contraignante et du montant des marchés sur l'intégration des considérations environnementales dans les DAOO, puis l'examen des effets marginaux et des odds ratios qui fournit une interprétation de l'ampleur et de l'importance relative des variables explicatives sur la probabilité d'intégration des considérations environnementales.

a) Estimation des coefficients

- Modèle logit

L'estimation des coefficients du modèle logit (Tableau n°1) met en évidence l'importance de la variable réglementation contraignante (REGL_CONTR), qui présente un coefficient positif et hautement significatif (β=5.423, p<0.001). Cela indique que l'existence d'une réglementation contraignante accroît fortement la probabilité d'intégration des clauses environnementales dans les marchés publics de travaux.

La variable montant du marché (MONTANT) présente également un effet positif mais d'ampleur réduite (β=1.093×10^{-10}), bien que sa significativité soit marginale (p≈0.057). Elle suggère que, toutes choses égales par ailleurs, les marchés de plus grande envergure sont légèrement plus susceptibles d'intégrer des considérations environnementales.

L'ordonnée à l'origine est négative et significative (β=−2.693, p<0.001). Ce résultat indique qu'en l'absence de facteurs explicatifs favorables (notamment sans réglementation contraignante), la probabilité d'intégrer des clauses environnementales est faible.

Tableau 1: Estimation des coefficients du modèle logit

Variable	Estimate	Std. Error	Z value	Pr ((>6 |***z|)
Intercept	-2.693×10^{0}	$5.686\times10^{-}{}_{0}{}^{1}$	−4.737	2.17×10−6 ***
REGL_CONTR	5.423×10^{0}	1.117×10^{0}	4.856	1.20×10−6 ***
MONTANT	1.093×10^{-10}	5.748×10^{-11}	1.902	0.0572

L'importance statistique de la réglementation contraignante confirme son rôle déterminant dans l'intégration effective de l'environnement.
*** : p < 0.001 ; ** : p < 0.01 ; * : p < 0.05 ; . : p < 0.1 : : non significatif

Les indicateurs globaux du modèle logit confirment une excellente qualité d'ajustement :

- Déviance nulle : 128.776 sur 93 degré de liberté (ddl = 93)
- Déviance résiduelle : 45.858 sur 91 degré de liberté (ddl = 91)
- AIC (Critères d'informations d'AKAIKE) : 51.858
- Nombre d'itérations de Fisher scoring : 7

Tableau 2 : Matrice de confusion logit

Prévision Observé	0	1
0	52	1
1	5	35

- Classe 0 correctement prédite : 52 (1 erreur)
- Classe 1 correctement prédite : 35 (5 erreurs)

La précision globale du modèle logit est estimée à 93 %. La matrice de confusion montre que le modèle logit prédit correctement 93 % des observations (52/53 pour la classe 0 et 35/40 pour la classe 1). Ce niveau de précision illustre sa capacité discriminante.

- Modèle probit

Le modèle probit a également été estimé en parallèle afin de comparer la robustesse des résultats. Les coefficients obtenus présentent des ordres de grandeur similaires à ceux du modèle logit, confirmant la stabilité des estimations (Tableau n°2)
La variable réglementation contraignante (REGL_CONTR) conserve un coefficient positif, élevé et hautement significatif (β = 3.012 ; p < 0.001), corroborant son rôle déterminant.
La variable montant du marché (MONTANT) apparaît également positive et significative à un seuil de 5 % ($\beta = 6.02\times10^{-11}$; p ≈ 0.051), ce qui renforce l'idée d'un effet secondaire mais présent des montants de marchés de grande envergure sur l'intégration environnementale.
L'ordonnée à l'origine demeure négative et très significative (β = −1.487 ; p < 0.001), confirmant la faible probabilité de prise en compte environnementale en l'absence de facteurs explicatifs favorables (notamment sans réglementation contraignante).

Tableau 3: Estimation des coefficients du modèle probit

Variable	Estimate	Std. Error	Z value	Pr ((>6 |***z|)
Intercept	−1.487	0.308	−4.824	1.41×10−6 ***
REGL_CONTR	3.012	0.642	4.689	2.74×10−6 ***
MONTANT	6.02×10−11	3.08×10−11	1.955	0.0507 *

- *** : p < 0.001 ; ** : p < 0.01 ; * : p < 0.05

Concernant les mesures globales d'ajustement :

- Déviance nulle : 128.776 sur 93 degré de liberté (ddl = 93)
- Déviance résiduelle : 46.102 sur 91 degré de liberté (ddl = 91)

- AIC (Critères d'informations d'AKAIKE) : 52.102

Tableau 4: Matrice de confusion probit

Prévision Observé	0	1
0	51	2
1	6	34

- Classe 0 correctement prédite : 51 (2 erreurs)
- Classe 1 correctement prédite : 34 (6 erreurs)

La précision globale du modèle probit révèle une précision globale de 91 %, légèrement inférieure au modèle logit.

b) Les effets marginaux ou les odds ratios

- Réglementation contraignante (REGL_CONTR) :
  - Dans le modèle Logit, l'existence d'une réglementation contraignante accroît la probabilité d'intégration d'une clause environnementale de 10,4 %, avec un odds ratio très significatif.
  - Dans le modèle Probit, l'effet est similaire, avec une probabilité accrue de l'ordre de 9,7 %.
- Montant du marché (MONTANT) :
  - Dans le modèle Logit, l'effet est positif mais significatif uniquement au seuil de 10 % ($p \approx 0{,}057$).
  - Dans le modèle Probit , il est significatif au seuil de 5 % ($p \approx 0{,}051$).

Dans les deux modèles, plus le montant du marché est élevé, plus la probabilité d'intégration environnementale augmente, mais cet effet demeure secondaire par rapport à la réglementation contraignante.

A cet égard, l'examen de la qualité d'ajustement des modèles a permis d'apprécier la robustesse des estimations et la fiabilité des prédictions. Les deux modèles présentent en effet une qualité d'ajustement élevée :

- Logit :
  - Log-vraisemblance ajustée = −22.93
  - Statistique du test de rapport de vraisemblance $G^2 = 82.92$
  - Pseudo R^2 McFadden = 0.644
  - Pseudo R^2 Nagelkerke = 0.786
- Probit :
  - Log-vraisemblance ajustée = −23.05
  - Statistique du test de rapport de vraisemblance $G^2 = 82.65$
  - Pseudo R^2 McFadden = 0.642
  - Pseudo R^2 Nagelkerke = 0.784

Le modèle logit se distingue légèrement par de meilleurs indicateurs de vraisemblance et une meilleure capacité prédictive, bien que le modèle probit fournisse des résultats très proches et cohérents. La convergence des deux modèles renforce la robustesse des conclusions : la réglementation contraignante constitue le facteur déterminant de l'intégration environnementale, tandis que le montant du marché exerce un effet secondaire mais significatif.

DISCUSSIONS

Les résultats issus des modèles logit et probit mettent clairement en évidence que l'intégration des considérations environnementales dans les marchés publics de travaux à Madagascar est fortement conditionnée par l'existence d'une réglementation contraignante.

En effet, la variable réglementation contraignante (REGL_CONTR) est fortement significative dans les deux modèles et exerce un effet positif robuste.

L'estimation des coefficients montre que cette variable (REGL_CONTR) est non seulement positive, mais aussi hautement significative, traduisant une probabilité accrue, de l'ordre de 10 % environ, d'intégrer des considérations environnementales lorsqu'une obligation réglementaire existe. Autrement dit, la probabilité d'intégrer des clauses environnementales augmente de manière substantielle lorsque le cadre juridique impose des obligations claires et contraignantes.

Le montant du marché (MONTANT) influent également sur l'intégration des considérations environnementales mais avec un effet secondaire, plus modeste. L'effet positif de cette variable traduit que les projets de grande envergure, généralement mieux encadrés et soumis à des exigences plus strictes, tendent à favoriser l'intégration de critères environnementaux.

Toutefois, sa significativité marginale (au seuil de 10 % dans le logit et de 5 % dans le probit) invite à considérer ce résultat avec prudence. Enfin, l'ordonnée à l'origine négative confirme que, sans contrainte ni incitation, la probabilité d'intégrer l'environnement demeure faible.

En termes de performance statistique, les deux modèles présentent des résultats cohérents et très proches, tant en termes de coefficients que de qualité d'ajustement. La comparaison logit et probit révèle cependant que le modèle logit offre une précision légèrement supérieure (93 % contre 91 %) et un meilleur ajustement global (R^2 de McFadden = 0.644 contre 0.642).

Ce constat rejoint la littérature méthodologique, qui souligne que les différences entre logit et probit sont généralement faibles, mais que le logit présente souvent une meilleure interprétabilité grâce aux odds ratios, plus facilement mobilisables dans une perspective de prise de décision publique.

L'analyse statistique logit-probit met ainsi en évidence deux conclusions majeures :

- Le cadre juridique clair et contraignant constitue le principal facteur pour assurer l'intégration effective des considérations environnementales dans les marchés publics de travaux.
- L'effet du montant du marché, bien que positif, reste secondaire et doit être interprété comme un facteur contextuel venant renforcer, mais non remplacer, la force du cadre juridique.

Ces conclusions rejoignent de nombreux travaux de recherche dans le champ des marchés publics durables. L'importance du cadre juridique est largement soutenue dans la littérature sur les marchés publics durables. Plusieurs études soulignent en effet que la contrainte réglementaire est l'élément décisif dans la généralisation des pratiques d'achats publics durables. Davies (2011) affirme que l'exigence réglementaire est un élément clé pour l'adoption de pratiques d'achats publics durables. Selon Testa et al, 2012, les réglementations soutiennent les autorités publiques pour le développement des achats publics durables.

Le cadre juridique joue donc un rôle fondamental dans la structuration, l'obligation et l'orientation des marchés publics vers une intégration effective des considérations environnementales. En établissant des règles, obligations et procédures explicites, il exerce un effet de levier déterminant en rendant incontournable l'insertion des critères environnementaux dans les DAO. S'agissant spécifiquement des marchés publics de travaux, les dispositifs juridiques doivent obliger notamment la prise en compte d'outils et procédures appropriés, notamment l'intégration des résultats d'études environnementales, tels que les études d'impact environnemental (EIE), qui renseignent sur les mesures d'atténuation, de compensation et les critères à intégrer dans les appels d'offre (Prieur, 2004).

Pour le cas de Madagascar, la législation environnementale oblige la réalisation d'études d'impact environnemental et la délivrance d'un Plan de Gestion Environnementale du projet pour certains

catégories travaux. Cependant, ces obligations ne sont pas encore formellement reconnues ni intégrées dans le Code des marchés publics, qui reste muet sur la prise en compte explicite des recommandations issues de ces études. Cette absence de coordination normative limite la portée opérationnelle de ces exigences environnementales dans le cadre des procédures de passation des marchés publics de travaux. Une meilleure articulation entre ces cadres juridiques permettrait donc d'assurer une mise en œuvre efficace, cohérente et contraignante des clauses et critères environnementaux, en garantissant que les exigences environnementales aient une force juridique claire dans toutes les phases du processus de passation et d'exécution des marchés.

Les résultats mettent donc en évidence une dépendance structurelle à la réglementation contraignante. Si celle-ci constitue un levier indispensable pour stimuler l'intégration des considérations environnementales, toutefois elle ne suffit pas à garantir la diversité ni la systématicité des instruments mobilisés. En effet, l'absence d'outils opérationnels, de formations adaptées et de sensibilisation des acteurs limite la capacité des acheteurs publics à concevoir et appliquer efficacement des clauses et critères environnementaux variés. De nombreux travaux de recherche convergent vers cette conclusion. Fournir des outils juridiques d'intégration des critères environnementaux constitue une condition déterminante, mais leur mise en œuvre effective requiert également des instruments méthodologiques et décisionnels ainsi qu'une formation adaptée des acteurs à tous les niveaux (Darnault et Malvy, 2020 ; Haddadi et al.). L'ensemble de la chaîne des achats doit ainsi développer une expertise en matière de marchés publics durables (Romestant et Oruezebala, 2018), tandis qu'une sensibilisation accrue favoriserait une utilisation élargie des outils disponibles (Sönnichsen et Clement, 2020). La compréhension des exigences réglementaires apparaît dès lors comme un levier essentiel pour l'adoption et la mise en œuvre des achats publics durables (Michelsen et De Boer, 2009).

CONCLUSION

L'analyse économétrique (logit et probit) menée sur une base de données de 94 DAOO lancés entre 2021 et 2023 par quatre ministères techniques met en évidence le rôle déterminant d'une réglementation contraignante dans l'intégration des considérations environnementales au sein des marchés publics de travaux à Madagascar.

Les résultats confirment l'hypothèse selon laquelle l'intégration actuelle des considérations environnementales dépend largement de l'existence d'une réglementation contraignante. En effet, la présence de clauses environnementales dans les DAOO est très fortement corrélée à l'existence d'obligations juridiques explicites. En l'absence d'un tel cadre normatif, les considérations environnementales demeurent marginales, ce qui souligne la prépondérance du facteur « réglementation contraignante » par rapport à d'autres déterminants potentiels, tels que la taille financière des projets.

Cette étude souligne ainsi l'importance d'un cadre juridique clair et contraignant pour promouvoir l'intégration effective des considérations environnementales dans les marchés publics de travaux. Une telle intégration constitue un enjeu majeur, car elle permet non seulement de limiter les impacts environnementaux des projets, mais également d'encourager l'adoption de pratiques de construction plus respectueuses de l'environnement, en cohérence avec les engagements internationaux de lutte contre le changement climatique.

Cependant, la seule existence d'une réglementation contraignante, aussi claire soit-elle, ne suffit pas. Pour que les marchés publics de travaux deviennent de véritables instruments de développement durable et de transition écologique, il est nécessaire de l'accompagner d'outils opérationnels adaptés, de renforcement des capacités des acteurs et de mécanismes de suivi rigoureux.

Il convient alors de se demander « comment renforcer l'articulation entre la législation environnementale et la législation des marchés publics afin de garantir une intégration plus

systématique et efficace des critères environnementaux dans l'ensemble des projets de travaux publics à Madagascar ».

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Philological Sciences

Языковая специфика категории измерения

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Вся познавательная деятельность человека, направленная на изучение объективной действительности, осуществляется в форме логических категорий.

Посредством языка предметы и явления материального мира отражаются в своём единстве с пространством и временем в сознании носителей этого языка. Эти универсальные понятия в каждой культуре связаны между собой, образуя своего рода «модель мира». С помощью этой модели люди воспринимают действительность и строят образ мира в своём сознании. Пространство и время, являясь важнейшими жизненными универсалиями всех культур, находят своё воплощение не только в художественных произведениях, но и во всех сферах жизни.

Как известно, всё многообразие пространственных отношений в объективной деятельности отражается через мышление человека. Как уже отмечалось, с современной точки зрения вся познавательная деятельность человека, направленная на изучение объективной действительности, осуществляется в форме логических категорий. Наиболее общие логические категории образуют систему взаимосвязанных понятий, выражающих универсальные формы бытия и познания. К числу таких категорий относится категория количества, одним из компонентов которой является категория
измерения. В философии измерение - это познавательный процесс, который определяет количественное отношение измеряемой величины к другой, служащей стандартом, эталоном. Согласно БЭС «измерение - это совокупность действий, выполняемых при помощи средств измерений с целью нахождения числового значения измеряемой величины чего-либо». Т.е. определение какой-либо мерой величины чего-либо. Когда вы что-то измеряете, вы сравниваете эту величину, с какой либо постоянной величиной. Эта постоянная величина называется единицей измерения [1,21].

Язык-набор определённых конвенциональных символов, выполняет функции коммуникации и познания. Является средством хранения и передачи информации, которое касается управления человеческим поведением, выражения самосознания личности.

Термин «язык», понимаемый в широком смысле, может применяться к произвольным знаковым системам, хотя чаще он используется для более узких классов знаковых систем. Знаковые системы — предмет изучения семиотики. Языки изучает лингвистика (языкознание).

Лингвистический аспект категории измерения характеризуется совокупностью способов её выражения языковыми средствами. Раскрытие значений слов, соотнесённых с понятием количества, посредством семантических компонентов тесно связано с сегментацией и дифференциацией. Значение общего количества сегментируется в направлении специфического - величина (количество), число (количество), мера (размер). Значение последних дифференцируется посредством единиц, соотнесённых с понятием общего количества и его частным проявлением. Категория измерения выступает как общее значение и реализуется группой семантических компонентов, образуя сложную структуру

семантического (понятийного) поля. Это семантическое поле категории измерения включает в себя следующие компоненты: размер, вес, объём, длина, ширина, высота, площадь, скорость.

Язык служит коммуникации и может быть назван коммуникативным процессом в чистом виде. Язык не существует вне культуры, это один из важнейших компонентов культуры, форма мышления, проявление специфической человеческой деятельности. Поэтому язык и культура нераздельны. Если язык - это культура, то и культура это язык.

Всякое произведение, выраженное с помощью языка, так сказать в слове, является плодом работы человека, свободно владеющего тем языком, на котором он пишет. Это свободное владение языком принимает самые разнообразные формы - в зависимости от эпохи, литературных принципов,
личности пишущего, назначения текста. Попытка перевести дословно то
или иной текст или отрезок текста приводят если не к полной непонятности 10этого текста, то, во всяком случае, к тяжеловесности и неясности. Слово отражает не сам предмет или явление окружающего мира, а то, как человек видит его, через призму той картины мира, которая существует в его сознании и которая определена его культурой. Безусловно, культурная картина мира всегда богаче, чем языковая. Но, именно в языке реализуется культурная картина мира, хранится и передаётся из поколения в поколение. Слова - это не просто названия предметов или явлений, а кусочек реальности, пропущенный через призму культурной картины мира и поэтому приобретший специфические, присущие только этому народу черты. Поэтому там, где русский человек видит два цвета: синий и голубой, англичанин видит один цвет -*blue.* Если англичанин видит два предмета – foot и leg то русский - только один - ногу. Один и тот же кусочек реальности, одно и то же понятие имеет разные формы языкового выражения в разных языках - более полные или менее полные. Слово как единица языка соотносится с предметом или явлением реального мира. В разных культурах могут быть разными не только предметы или явления, но и культурные представления о них. Любуясь природой, человек давно заметил в ней бесконечное множество интересных, причудливых форм и цветовых оттенков. Например казахи используют слово «көк - голубой» для обозначения цвета травы и неба, а русские говорят «голубое небо и зеленая трава». Голубой фон символизирует различные тюркские народы, входящие в состав современного населения страны, в их числе казахи, татары, монголы, уйгуры и другие. У этих народов голубой цвет традиционно имеет религиозное значение, и олицетворяет бога неба Тенгри, "вечно широкое голубое небо", а также воду. Светло-голубой цвет также символизирует культурное и этническое единство казахского народа. Казахи связывали голубой цвет с предметом, т.е. особенно при выборе тканей. Так английский «house» очень отличается от русского «дома». Для русских дом это и место жительства, и место работы человека, любое здание и учреждение. Для англичан - это только здание или строение. Домашний очаг будет передаваться словом «home», а также например для немца слово „Raum“ означает пространство, космос, место, помещение, комната, емкость, зона, то для казаха оно имеет только одно значение – «кеңістік» пространство.

С развитием торговых отношений, особенно в текстильной промышленности между иностранными государствами потребовалось создание единых эталонов. Первая в мире единица измерений, не основанная на пропорциях человеческого тела - это единица названная метром. Отсюда название системы мер, основанной на мере – метрическая система (современный вариант называется система измерения СИ). Во Франции в 1789 году была принята международная система измерения длины, веса и объема. Она получила название «метрической системы». Теперь большинство стран используют ее. Метрическая система использует метр как основную единицу измерения. Один метр равен 39,37 дюймам.

Базируется эта система измерения на цифре 10; каждая последующая единица измерения в 10 раз больше предыдущей (например, один метр равен 10 дециметрам или 100 см). ЕИ в разных языках могут быть выражены лексическими единицами, так называемыми народными мерами измерения как (локоть - древнюю меру *"локоть"* продолжали еще употреблять для измерения сукна, полотна и шерстяных тканей домашнего изготовления. Как следует из "Торговой книги" три локтя приравниваются двум аршинам, применялись также *шаг, метр, сантиметр, дециметр, миллиметр, елі, inch.*

Они относятся к лексическим средствам, *в мгновенье ока, бес құлаш шұға мата, вержение камня, оқ бойы* относятся к лексико-грамматическим. Аршин был в России центральной метрической единицей. Он пришел на смену локтю, который еще на рубеже XV-XVI веков был официально-торговой и народно бытовой мерой. Аршин восходит к персидскому слову со значением длина всей руки от плеча. Аршином мерили восточные ткани. ЕИ являются в любом тексте носителями информации об определенном расстоянии, весе, объеме, и т.д. Соматический способ (с использованием различных частей тела) измерения пространства является одним из самых популярных способов измерения окружающего пространства.

Во второй половине XVII века аршин проник в различные отрасли производства, особенно в текстильную промышленность, где его применяли совместно с *вершком.* Мера *вершок* – верхняя часть пальца от конца до среднего сустава (в БЭС – 4,44 см) широко применялась в быту. Ширина и длина пальца также широко употреблялась для измерений. В английском языке мы встречаем ЕИ *hand* (как ладонь) = 10,16 см и *finger* - длина (4,5дюйма) и ширина (3/4 дюйма) пальца. В качестве длины дюйма в Англии использовали большой палец. Единицами в текстильной промышленности в казахском языке послужили слова *қар* = 30-40 см, длина предплечья (от плеча до локтевого сустава) и *шынтақ* –мера длины от кончика среднего пальца до локтевого сгиба, а также *сүйем* обозначает расстояние между большим и указательным пальцами.- *Құрылатын тор мықты иірілген жіңішке жібек, кендір жіптерден, көздері бүркіт өтіп кетпейтіндей сүйем шаршы (15х15 см) мөлшерінде түйіліп тоқылады.*

В разных областях человеческой деятельности применялись разные меры. Например в текстильной использовались не только народные меры измерения как *аршин* или *локоть*, но и также другие денежные единицы, например в торговле *гроша, шиллинг, алтын, вацен* и *фунт, пуд, меру, бочку* и *ведро* т.д. В аптечном деле применяли *золотник* и *гарнец*. В англоязычной литературе можно встретить также множество денежных единиц, которые популярны и можно услышать везде, например слово *penny* в составе некоторых фразеологизмов имеет разные значения. *Penny cost a pretty penny – ударить по карману; to look twice at every penny- жалеть каждую копейку.* В казахском языке тоже можно встретить названия денежных единиц в составе фразеологизмов с различными толкованиями. Например: *Тыныннан теңге жиналар – копейка рубль бережет* или *көк соқыр тиыны жоқ жанында – без гроши или пұлсыз күнің қараң – без денегжить не возможно.*

Сколько национальностей и столько же культур. Каждая культура имеет свою языковую систему, с помощью которой её носители имеют возможность общаться друг с другом.

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Les locutions phraséologiques avec des noms de fruits en azerbaïdjanais et en français

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Mots cles: Locutions phraséologiques, noms de fruits, langue azerbaïdjanaise, langue française, analyse contrastive, expression idiomatique, métaphore lexicale

Les langues reflètent la culture, la mentalité et l'expérience de leurs locuteurs à travers différents moyens d'expression. Parmi eux, les locutions phraséologiques jouent un rôle fondamental, car elles transmettent non seulement un sens figuré mais aussi une vision du monde. Les noms de fruits, étroitement liés à la vie quotidienne et à la symbolique des peuples, apparaissent fréquemment dans les expressions idiomatiques. La langue est un système de signes qui possède des valeurs culturelles. Dans l'enrichissement de la langue et pour exprimer la pensée et le discours avec plus de précision, les groupes de mots jouent, aux côtés des mots, un rôle irremplaçable.

L'objectif de cet article est d'analyser comparativement l'usage des noms de fruits dans les locutions phraséologiques de la langue française et de la langue azerbaïdjanaise, afin de mettre en évidence leurs convergences et divergences culturelles et linguistiques. La spécificité de la composition lexicale dans les langues étudiées réside dans le fait que, à travers les noms de fruits, elle reflète de manière fidèle les caractéristiques historiques, culturelles et ethnographiques des peuples. Dans les langues étudiées, les noms de fruits apparaissent, d'un point de vue structurel, sous des formes simples, dérivées et composées, et parmi celles-ci, les formes simples sont considérées comme des structures de base.

Nous allons faire les ccaractéristiques générales des locutions phraséologiques. La locution phraséologique se définit comme une combinaison stable de mots dont le sens global ne découle pas uniquement de la somme des significations des composants. Les noms de fruits, en raison de leur charge symbolique universelle (fécondité, douceur, fragilité, abondance), sont souvent utilisés pour exprimer des qualités humaines, des situations de la vie quotidienne ou des jugements de valeur. Les fruits dans la phraséologie azerbaïdjanaise

Dans la tradition azerbaïdjanaise, les fruits sont fréquemment associés à des proverbes et maximes populaires à valeur didactique. -*Alma atanı daş atmazlar* (« On ne jette pas de pierres à celui qui offre une pomme ») – souligne l'importance de la gratitude et de la bienveillance.

-*Üzüm üzümdən qaralır* (« Le raisin noircit du raisin ») – illustre le phénomène d'imitation entre les individus.

-*Armud biş, ağzıma düş* (« Poire, mûris et tombe dans ma bouche ») – critique l'attente passive et le refus de l'effort.

-*Nar kimi partlamaq* (« éclater comme une grenade ») – exprime une colère soudaine.

Ces exemples montrent que les fruits dans la phraséologie azerbaïdjanaise véhiculent surtout des leçons de sagesse populaire, liées au travail, aux relations sociales et à la patience.

Expressions phraséologiques avec des noms de fruits en azerbaïdjanais et en français

-Expression avec abricot (*ərik*) en azerbaidjananais- *Ərik ağacına çıxmaq* → « Monter à l'abricotier » → Se lancer dans une tâche difficile.

Expression avec abricot en français : *Ce n'est pas l'abricot de l'année* (rare) → Ce n'est pas ce qu'on attendait.

Expression phraséologique avec mûre / mûrier (*tut*)

-en azerbaidjanais : *Tut ağacından yapışmaq* → « S'accrocher au mûrier » → Se lancer dans une affaire compliquée.

-en français : *Haut comme trois pommes* (parfois avec « mûres ») → Être très petit de taille.

Expression avec kaki (*xurma*)

-en azerbaïdjanais: *Xurma kimi yumşaq* → « Doux comme un kaki » → Être très fragile, sensible.

-en français : Peu d'expressions avec « kaki » ; on dit plutôt *doux comme une poire bien mûre*.

Expression phraséologique avec raisin (*üzüm*)

-en azerbaidjanais : *Üzüm üzümdən qaralır* → « Le raisin noircit du raisin » → Les gens s'influencent mutuellement.

-en français : *Manger des raisins verts* → Être impatient.

Expression phraséologique avec fraise (*çiyələk*)

-en azerbaïdjanais: *Çiyələk kimi qırmızı* → « Rouge comme une fraise » → Très rouge (comparaison).

-en français : *Ramener sa fraise* → Se mêler d'une conversation, intervenir sans y être invité.

Expression avec amande (*badam*)

-en azerbaïdjanais: Badam *gözlü* → « Œil en amande » → Des yeux noirs et brillants.

-en français : *Les yeux en amandes*→ En amande est une expression qui est toujours précédée du terme yeux, on parle en effet d'yeux en amande pour désigner des yeux allongés, donc arborant la forme du fruit dont il est question dans l'expression.

Expression avec pêche (*şaftalı*)

en azerbaïdjanais: *Şaftalı kimi yumşaq* → « Doux comme une pêche » → Très tendre, délicat.

-en français : *Avoir la pêche* → Être en pleine forme, avoir de l'énergie. *Être une bonne pêche* (fam.) → Être attirant, séduisant.

Expression avec coing (*heyva*)

-en azerbaïdjanais : *Heyva kimi saralmağa başlamaq* → « Devenir jaune comme un coing » → Pâlir de peur ou de maladie.

-en français : *Jaune comme un coing* → Très jaune.

Les fruits dans la phraséologie française

En français, les fruits apparaissent davantage dans des locutions idiomatiques à caractère imagé et expressif. Les expressions phraséologiques en français utilisant des noms de fruits incluent "avoir la pêche" (être en forme), "avoir la banane" (être heureux et sourire), "tomber dans les pommes" (s'évanouir), "se fendre la poire" (éclater de rire), "pour des prunes" (pour rien, en vain), "une République bananière" (un pays dirigé par un gouvernement corrompu), "ramener sa fraise" (intervenir de manière inopportune), et "avoir le melon" (être vaniteux), *Être une bonne poire* – être naïf, trop indulgent, *La prunelle de ses yeux* – ce qu'on chérit le plus. Ces expressions relèvent moins de la sagesse populaire que d'un imaginaire métaphorique propre à la langue française, souvent humoristique et expressif. Dans cet article le but est de faire l'analyse comparative des locutions phraséologiques utilisées avec les noms de fruits dans deux langues différentes. La comparaison entre les deux langues révèle plusieurs traits distinctifs :

-Similarité thématique : certaines valeurs sont communes, par exemple la *poire* renvoie dans les deux cultures à la naïveté ou à la passivité.

-Spécificité culturelle : les fruits utilisés ne sont pas toujours identiques : la grenade (*nar*) en azerbaïdjanais a une forte valeur symbolique, tandis que le français privilégie la pomme, la poire, la cerise ou la prunelle.

-Fonction discursive : les locutions azerbaïdjanaises remplissent souvent une fonction didactique et proverbiale, tandis que les locutions françaises ont une visée expressive et imagée.

Valeurs symboliques

En azerbaïdjanais : les fruits expriment la patience, la sagesse populaire, la moralité. Exemple : *Alma atanı daş atmazlar* → on ne fait pas de mal à celui qui fait du bien.

En français : les fruits expriment souvent des états émotionnels, physiques ou des jugements sociaux. Exemple : *Être une bonne poire* → être naïf. *La cerise sur le gâteau* → élément supplémentaire positif.

Le choix des fruits dans les locutions phraséologiques dans deux langues sont différent. En azerbaïdjanais les fruits reflètent surtout la réalité agricole et culturelle du Caucase : grenade (*nar*), abricot (*ərik*), raisin (*üzüm*), mûre (*tut*), coing (*heyva*), etc. En français on retrouve plutôt les fruits communs au climat tempéré : pomme (*pomme*), poire, cerise, prune, pêche et les noms de autres fruits. Par exemple, la grenade est fréquente en azerbaïdjanais, mais absente en français ; inversement, la cerise et la prunelle sont courantes en français mais marginales en azerbaïdjanais. En azerbaïdjanais les expressions sont souvent des proverbes ou des dictons populaires à valeur éducative ou morale. En français les locutions sont surtout des idiomes expressifs utilisés dans le langage courant, parfois humoristiques. Par exemple, *Tomber dans les pommes* → s'évanouir.

La mise en parallèle des locutions phraséologiques en azerbaïdjanais et en français révèle une universalité thématique liée à la nature, mais également une spécificité culturelle qui façonne les choix lexicaux et symboliques. Les fruits deviennent des vecteurs de représentations sociales : sagesse et morale dans le monde azerbaïdjanais, imaginaire expressif et idiomatique dans le monde français. Les noms de fruits se manifestent également par leur activité métaphorique et stylistique. Cette particularité se reflète tant dans leur nomination que dans le processus créatif et l'utilisation qui en est faite au moment de l'expression.

Difficultés de traduction

Traduire une locution phraséologique d'une langue à une autre peut être difficile, car le vocabulaire et la structure grammaticale des deux langues sont différents. La traduction des locutions phraséologiques d'une langue à une autre présente souvent des difficultés majeures. Ces difficultés s'expliquent par les différences lexicales, grammaticales et culturelles entre les langues. Une expression figée dans une langue peut ne pas avoir d'équivalent direct dans l'autre, et son sens littéral ne reflète pas toujours sa valeur figurative. Par exemple, les locutions contenant des noms de fruits peuvent véhiculer des connotations culturelles spécifiques qui sont difficiles à restituer dans une autre langue sans perdre le sens ou la couleur stylistique originale. Il faut chercher des méthodes de traduction, les équivalents des expressions dans ces deux langues.

Conclusion

L'étude des locutions phraséologiques construites autour des noms de fruits en azerbaïdjanais et en français montre que, si les deux langues exploitent un champ sémantique commun lié à la nature et à la vie quotidienne, elles se distinguent par la fonction assignée à ces expressions. L'azerbaïdjanais privilégie la sagesse populaire et l'enseignement moral, alors que le français met l'accent sur l'expressivité et la métaphore. Cette analyse comparative illustre la richesse interculturelle de la phraséologie et confirme que les fruits, universels dans la vie humaine, trouvent dans chaque langue une résonance particulière façonnée par la culture et l'histoire des peuples. Les différences majeures montrent qu'en azerbaïdjanais, les fruits sont utilisés comme support d'une philosophie de vie transmise par les proverbes. En français, les fruits servent surtout à enrichir l'expression idiomatique du quotidien, souvent de façon imagée ou humoristique.

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Technical Sciences

AUTOMATIC PREVENTION OF TRANSIENT STABILITY VIOLATION BASED ON THE RESULTS OF THE STABILITY MARGIN MONITORING SYSTEM CALCULATIONS

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Abstract

In modern conditions of development of the electric power industry, the problem of ensuring the transient stability of energy systems is becoming particularly relevant. Traditional methods of emergency automation based on fixed threshold values of parameters are not effective enough with a significant reduction in system inertia due to the integration of renewable energy sources (RES) and the decommissioning of synchronous generators. The study considers the need to move from static control algorithms to adaptive methods using real-time monitoring data. The basis of the proposed approach is the stability reserve monitoring system (SMMS), which provides the calculation of critical voltage angles between nodes of the power system based on WAMS and SCADA data. This allows you to dynamically adjust the emergency response parameters, taking into account the current state of the power system and its inertia. The practical significance of the work is confirmed by the example of modeling transients in the Mangystau power system of Kazakhstan. The results show that when the moment of inertia decreases, the system loses synchronism, however, the use of an adaptive algorithm with a metered load shutdown (for example, 300 MW) makes it possible to restore stability and prevent asynchronous operation. At the same time, smaller volumes of shutdowns are insufficient, which underlines the importance of fine-tuning control actions. The proposed method reduces the likelihood of excessive load disconnection and ensures higher reliability and efficiency of the power system. Despite the risks associated with telemetry system failures, the choice of shutdown volume or the reversal of power flows, adaptive control forms the modern basis for preventing cascading accidents and increasing the stability of energy systems with a high proportion of renewable energy sources.

Keywords: steady-state stability, transient stability, stability margin monitoring system, emergency automation, inertia constant, inverter-based resources.

1. Introduction and background

The problem of ensuring the stability of parallel operation of electric power systems is one of the key tasks that has been relevant since the creation of the first global energy systems. Disruption of the stability of parallel operation leads to a loss of synchronism of generators in different parts of the power system, which causes the generators to switch to asynchronous mode with different angular speeds of the rotors. Asynchronous mode is defined as the most critical, since it is accompanied by significant voltage fluctuations at the nodal points of the network [1], which, ultimately, can lead to the shutdown of auxiliary units of thermal and nuclear power plants [2].

To ensure the stability of power systems, principles of emergency control have been developed, aimed at preventing the disruption of stability by implementing control actions. Such impacts include disconnecting consumers in scarce and generators in redundant areas of the power system, automatic loading of generators, boosting excitation, and control of reactive power compensation devices [3]. Fixed events, such as line disconnection, as well as parameters of power overflows through intersystem connections and voltage in nodes, are usually used as signals to trigger control actions. At the same time, the threshold values of the parameters at which the control actions are activated are usually calculated by engineers in advance and based on the condition of ensuring stability in the initial and post-emergency modes with the most unfavorable combinations of regime and balance factors.

However, in conditions of high integration of inertia–free renewable energy sources (hereinafter referred to as RES) and decommissioning of thermal power plants with synchronous generators, the problem of transient stability is of particular importance [4, 5]. Assuming that RES provide sufficient reactive power compensation, voltage maintenance and have a reserve of active power in storage systems, the problem of steady-state stability can be effectively solved. Nevertheless, if earlier, with the high inertia of the power system, ensuring steady-state stability guaranteed transient stability, then reducing the moment of inertia calls into question the fulfillment of this condition. According to the equation of motion of the rotor, the acceleration of the change in the angle of the rotor under the action of perturbations is inversely proportional to the value of the moment of inertia. Consequently, reducing the moment of inertia increases the likelihood of the rotor reaching a critical angle and losing the synchronism of the generator or group of generators.

With the rapid development of communication systems and digital technologies, network observability is significantly increased thanks to systems such as Supervisory Control and Data Acquisition (hereinafter referred to as SCADA) and Wide Area Monitoring System (hereinafter referred to as WAMS). With the development of these technologies, it becomes possible to implement systems that perform centralized analysis of data on electrical parameters and their subsequent processing. One of these technologies is the Stability Margin Monitoring System (hereinafter referred to as the SMMS).

SMMS is a software and hardware complex that performs real—time steady-state and stability calculations based on telemetry data. The works [6, 7, 8, 9] describe in detail the fundamental concepts and the principle of the SMMS operation. Based on the results of the SMMS calculations, it becomes possible to use adaptive response parameters of emergency automation to prevent transient stability by implementing control actions. Within the framework of this work, it is proposed to continue the study of the transient stability of the Mangystau power system of Kazakhstan [4, 5] by presenting a description of the new principle of adaptive emergency control, which had not previously been implemented in the power system of Kazakhstan.

The main contributions of this paper can be summarized as follows:

1) solving new problems related to transient stability arising from the widespread use of non-inertia renewable energy sources;

2) the proposal of new principles of adaptive emergency management based on WAMS and a real–time stability calculation module - the transition from traditional fixed threshold values of launch parameters to dynamically adjusted settings;

3) confirmation of the effectiveness of adaptive emergency management to maintain transient stability based on simulation results;

4) reducing the probability of excessive load shutdown caused by fixed threshold values of electrical parameters calculated in advance.

The proposed principle is based on the calculation results of the stability control system and the voltage angle parameters obtained using WAMS. The rest of the paper is structured as follows. Section 2 describes the methodology for calculating transients, which describes the initial and post-emergency mode, the sequence of inertia reduction to achieve a scenario of disruption of transient stability, explains the implementation of the control actions of emergency automation and the simulation commands themselves in the Power World Simulator 23 software. Section 3 describes the results and discussions of transient calculations for various scenarios and explains them in terms of angular transmission characteristics. In section 4 conclusion remarks are presented.

2. Methodology

2.1. Steady-state modes under research

For analysis purposes this paper refers to the computational model of the Mangystau power system (Kazakhstan) developed in [4]. The initial parameters of the power system mode is as follows (Figure 1):

1) Generation – 775 MW;

2) Consumption – 950 MW;

3) Transfer of power through intersystem lines between Station 3 220kV and Substation 4 – 183 MW towards Station 3;

4) The voltage angle between the Station 3 220kV and Substation 4 (hereinafter referred to as δ) is 17.157 degrees.

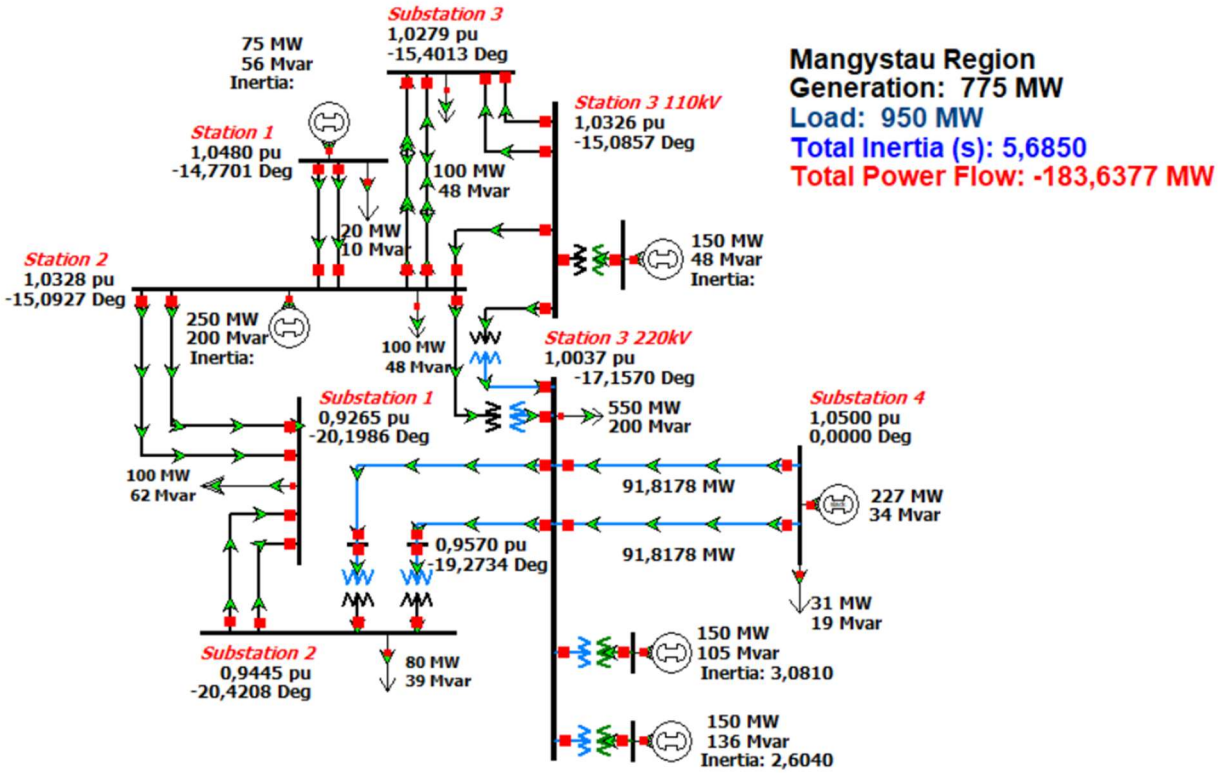


Figure 1. Initial operation mode of Mangystau power system

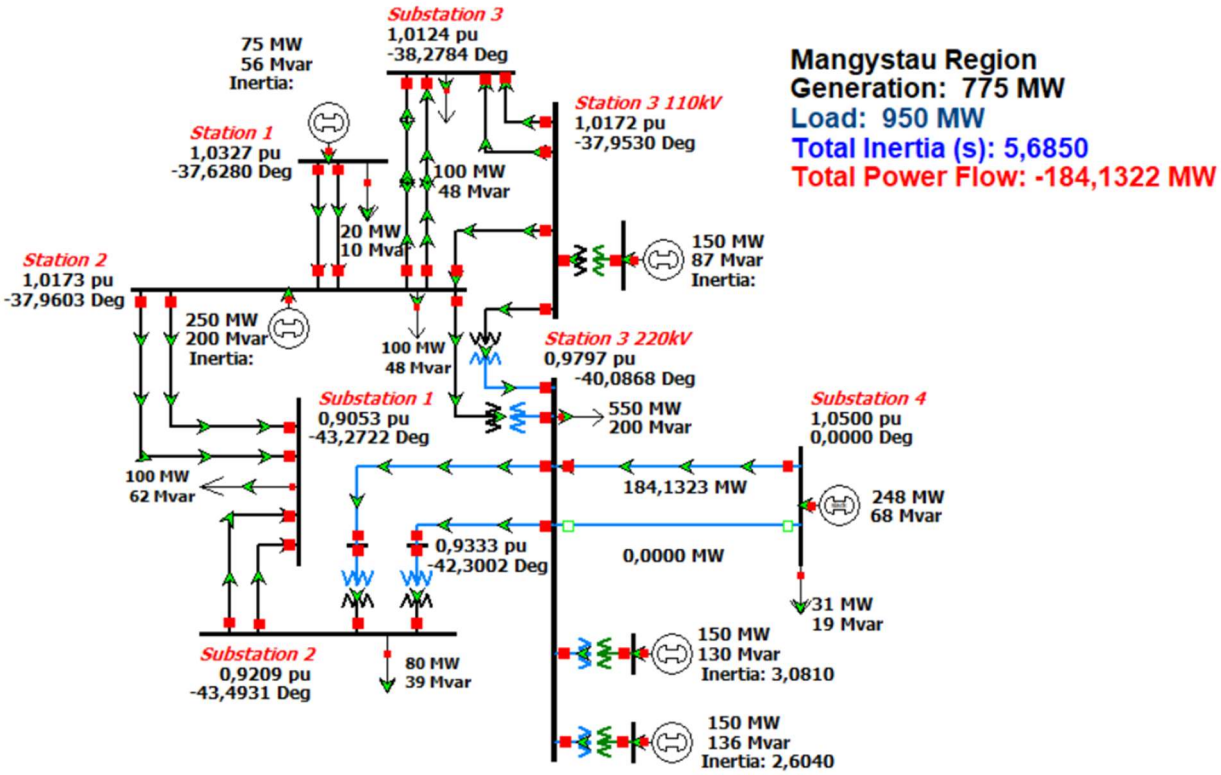


Figure 2. Post-emergency mode after disconnection of one of the 220 kV interconnect lines

The emergency mode of operation of this circuit is the emergency shutdown of one of the 220 kV interconnect lines. After disconnection, the circuit weakens, and all the power flowing through the disconnected line is transferred to a parallel undamaged line. According to the Newton-Raphson method the solution of regime in the post-accident regime has convergence, so we can assume that the steady-state stability is preserved. However, due to the weakening of the circuit and the decrease in the angular characteristic, the voltage angle δ increases from 17.157 to 40.08 degrees. The electrical parameters in the post-emergency mode are shown on Figure 2.

Thus, using expression $\delta_{crit} = 180 - \delta_{post\text{-}emergency}$, it is possible to calculate the critical stress angle according to the criterion of transient stability (140 degrees). Therefore, this angle parameter can be integrated into an emergency automation system that implements a control action using a special load shedding automation (SLSA).

2.2. Reducing the inertia constant and implementation of control actions

After determining the analyzed steady-state regime in the initial and post-emergency modes, it is necessary to determine the scenario of a violation of transient stability. When all the synchronous generators in the power system are rotating, the moment of inertia is large enough to maintain transient stability. The proposed methodology refers to gradual reduce of the moment of inertia by replacing the mathematical model of synchronous generators with an inverter based resource (IBR). The procedure and methodology for reducing the moment of inertia are described in detail in [4, 5]. In this work the following four scenarios of inertia moment value modification are considered:

1) H = 22.26 s – all the synchronous generators connected to the grid;
2) H = 10.78 s – two generators on Station 2 are replaced;
3) H = 8.76 s – all generators on Station 1 are replaced;
4) H = 5.68 s – a generator on 110kV Station 3 is replaced.

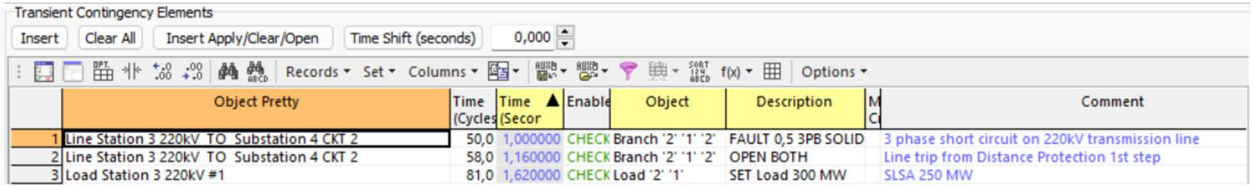
Having determined the moment of inertia of the power system, at which transient stability is disrupted, it becomes necessary to apply control actions to the objects of the electrical network

to prevent this violation. Control actions are formed using an emergency automation system that includes automatic dosing of control actions. The registration of the fact of disconnection of the 220 kV line and the value of the voltage angle δ are accepted as the starting element. If, during an emergency shutdown of the 220 kV line, the value of the voltage angle δ exceeds the critical value calculated by the SMMS, the load from the SLSA is disconnected by an amount sufficient to maintain stability. In this paper, the load shutdown values of 250 and 300 MW are considered.

2.3. Simulator tuning

In the first second of the simulation, a three-phase short circuit occurs at 0.5% of the 220 kV line distance between Station 3 220 kV and Substation 4. The value of 0.5% of the distance is chosen based on the greatest possible severity of the damage scenario. Considering that the type of short circuit is three-phase, there is a high probability that this type of damage occurs on the line disconnectors (for example, if the fixed grounding is not removed after repairs).

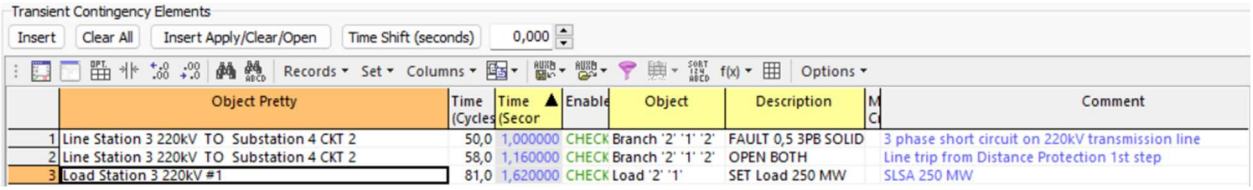
Then the first step of distance protection operates, which trips the circuit breaker on the Station 3 side and sends a fast remote trip signal on the Substation 4 side via high-frequency automation channels. Taking into account the action time of the contacts of the output protection relays and the circuit breaker (oil type) trip, the disconnection time of the damaged line is 0.16 seconds.


Transient Contingency Elements

Insert | Clear All | Insert Apply/Clear/Open | Time Shift (seconds) 0,000 | Records | Set | Columns | f(x) | Options

	Object Pretty	Time (Cycles	Time (Secor	Enable	Object	Description	M C	Comment
1	Line Station 3 220kV TO Substation 4 CKT 2	50,0	1,000000	CHECK	Branch '2' '1' '2'	FAULT 0,5 3PB SOLID		3 phase short circuit on 220kV transmission line
2	Line Station 3 220kV TO Substation 4 CKT 2	58,0	1,160000	CHECK	Branch '2' '1' '2'	OPEN BOTH		Line trip from Distance Protection 1st step
3	Load Station 3 220kV #1	81,0	1,620000	CHECK	Load '2' '1'	SET Load 300 MW		SLSA 250 MW

Figure 3. 250 MW load shedding modelling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	Object Pretty	Time (Cycles	Time (Secor	Enable	Object	Description	M C	Comment
1	Line Station 3 220kV TO Substation 4 CKT 2	50,0	1,000000	CHECK	Branch '2' '1' '2'	FAULT 0,5 3PB SOLID		3 phase short circuit on 220kV transmission line
2	Line Station 3 220kV TO Substation 4 CKT 2	58,0	1,160000	CHECK	Branch '2' '1' '2'	OPEN BOTH		Line trip from Distance Protection 1st step
3	Load Station 3 220kV #1	81,0	1,620000	CHECK	Load '2' '1'	SET Load 250 MW		SLSA 250 MW

Figure 4. 300 MW load shedding modelling

Figures 3 and 4 show the simulation actions for 250 MW and 300 MW load relief scenarios after disconnection of the 220 kV line. When simulating a stability violation without the use of control actions, the voltage angle δ reaches 140 degrees 0.46 seconds after the line is disconnected. Thus, at 1.62 seconds of simulation, two load relief scenarios are implemented to prevent instability. It is assumed that a 250 MW load dump is insufficient to prevent instability, while a 300 MW load dump helps maintain transient stability.

3. Results and discussion

Figure 5 shows fluctuations in the stress angle within the framework of four scenarios defined in accordance with the Methodology, with decreasing values of the moment of inertia. The first three scenarios ensure that the transient stability of the energy system is maintained. The plots illustrate that at a moment of inertia of 22.26 s, voltage angle fluctuations exhibit stable behavior with acceptable deviations. With a decrease in the moment of inertia to 10.78 and 8.76 s, there is a significant increase in the amplitude of voltage angle deviations, as well as a shift in the extreme both in amplitude and in time to reach it. This indicates that with decrease in the moment of inertia, the amplitude of the maximum deviation of the voltage angle increases, and the moment of its achievement occurs earlier. In the latest scenario, at a moment of inertia of 5.68 s, a loss of synchronism is recorded, the system goes into asynchronous mode, at which the voltage angle exceeds 180°, without returning to a steady state.

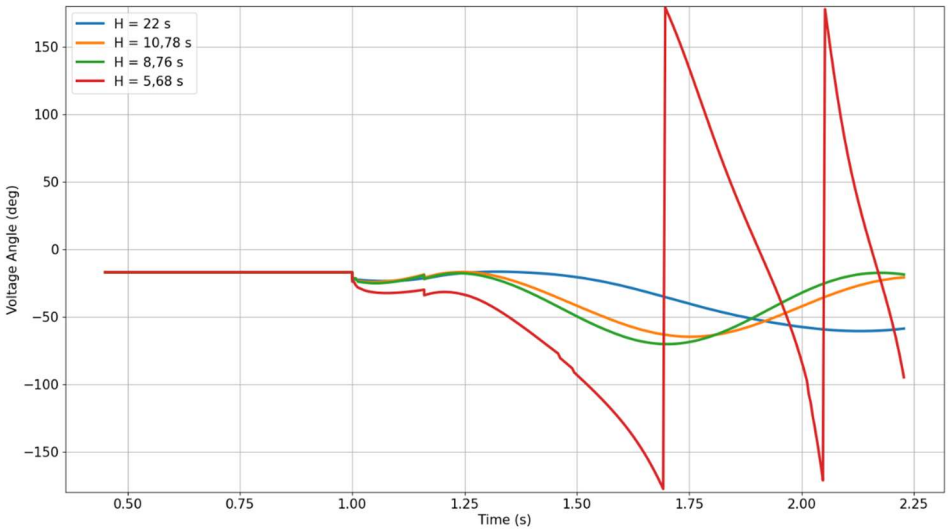


Figure 5. Voltage angle fluctuations with decreasing magnitude of inertia constant

Figure 6 shows the characteristics of changing the voltage angle with an inertia constant of 5.68 s under conditions of impaired transient stability, as well as during the implementation of emergency automation measures that turn off the 250 and 300 MW loads by 1.62 s. The plots show that turning off the 250 MW load was insufficient to compensate for the excess kinetic energy accumulated in the generator rotors in short-circuit mode short circuits. As a result, the voltage angle continues to increase, reaching 180°, which indicates that the system is switching to asynchronous mode. Switching off the 300 MW load, on the contrary, provides the necessary energy balance: the braking area of the generator in the transient process exceeds the area of its acceleration. This allows you to maintain the transient stability of the system, while the voltage angle stabilizes and smoothly transitions to a new stable state.

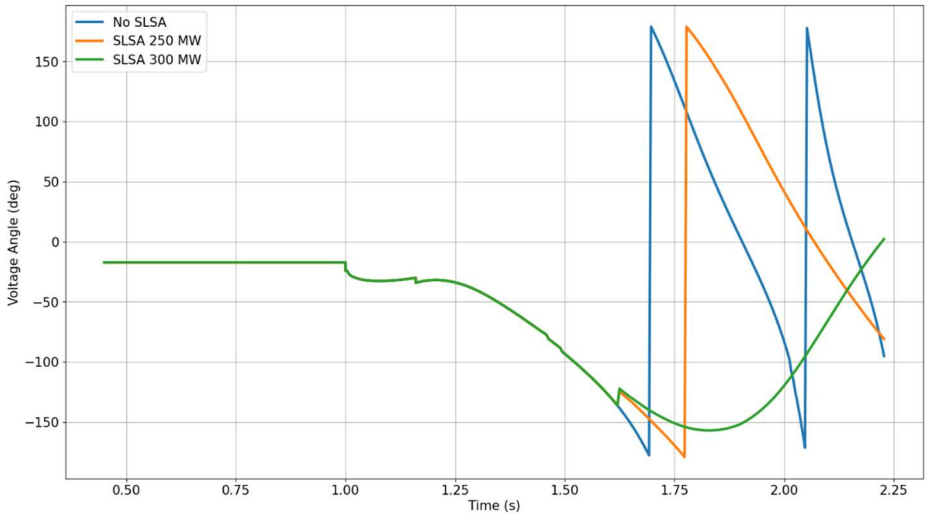
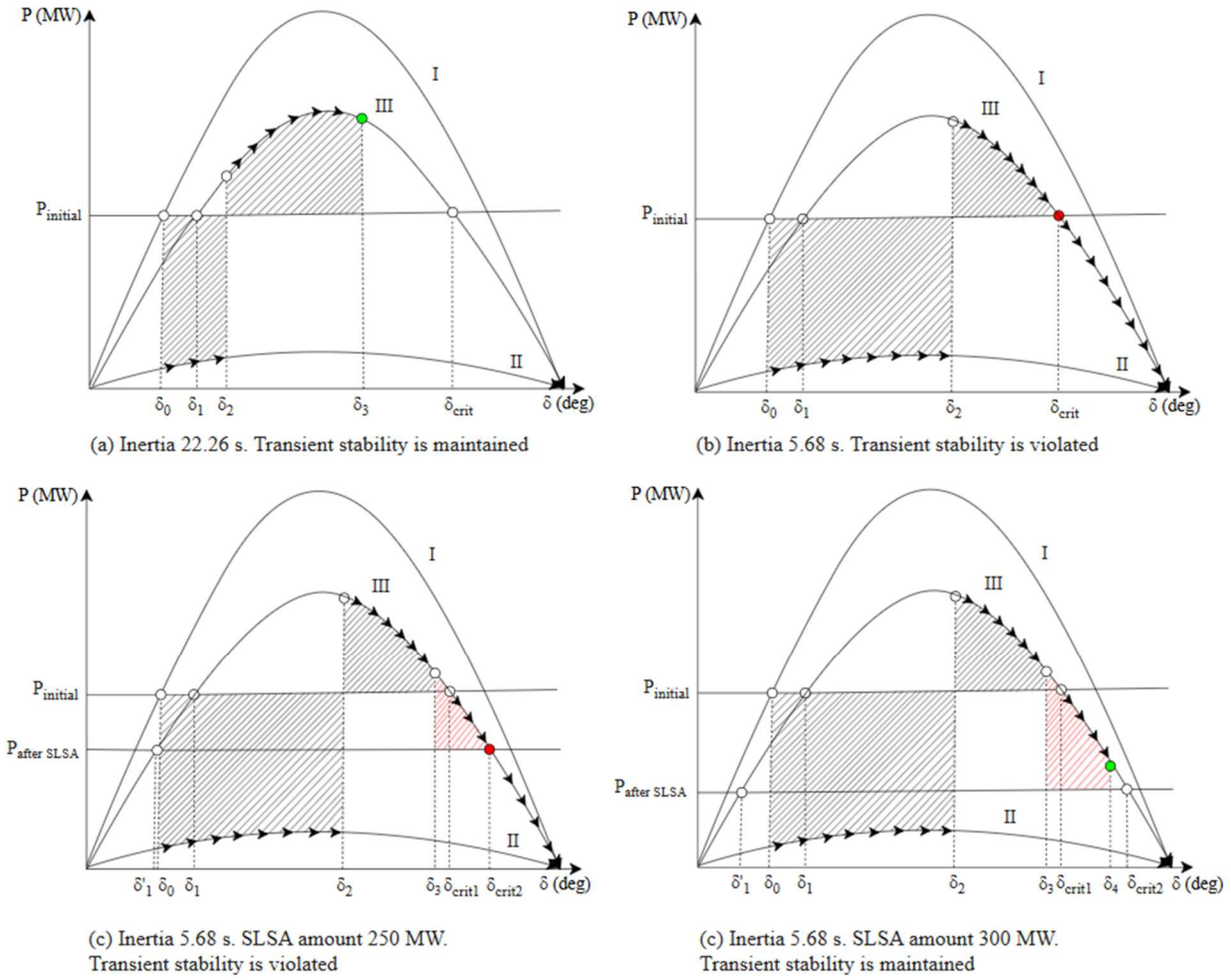


Figure 6. Voltage angle fluctuations with and without control actions

The simulation results are demonstrated in the angular characteristics of the power transmission network shown on Figure 7.

According to Figure 7 (a), the power system involves all synchronously operating generators at Stations 1, 2 and 3. The total inertia constant in this scenario is 22 s. In this angular characteristic, δ_0 is the voltage angle in the initial mode (17.157 degrees), and δ_1 – the angle in the post-emergency mode. When a short circuit occurs on one of the 220 kV lines, the angular characteristic decreases dramatically and takes the form II. The angle begins to increase to the value of δ_3 – the moment of short circuit disconnection by the action of the relay protection. After

disconnection, the characteristic takes the form III, and the angle, due to braking process of synchronous generators, continues to increase until the moment when all the kinetic energy of rotor rotation stored during the short circuit is exhausted (at the angle δ_3). In this scenario, due to a sufficiently high inertia constant, transient stability is maintained and the angle returns to the value of δ_1.



(a) Inertia 22.26 s. Transient stability is maintained

(b) Inertia 5.68 s. Transient stability is violated

(c) Inertia 5.68 s. SLSA amount 250 MW. Transient stability is violated

(c) Inertia 5.68 s. SLSA amount 300 MW. Transient stability is maintained

Figure 7. Angular characteristics (P vs. δ) for aggregated interconnect lines for 4 scenarios

In (b) it is shown the behavior of the angles on the angular characteristics in the scenario where several synchronous generators were replaced by IBG and the total inertia diminished to 5.68 s. In this case, the rate of change of the angle during a short circuit escalates significantly due to the inverse proportionality to the inertia constant of the system. Consequently, the angle δ_2 takes on a larger value, which in turn remarkably enlarges the acceleration area of the generators and reduces the reserve of the deceleration area. As a result, the stored kinetic energy becomes too large for this electrical network, and the angle δ_3 exceeds δ_{crit} and is never achieved, which causes the occurrence of an asynchronous mode.

Figure (c) applies a control exposure that disconnects a fixed amount of load via special load shedding automation with 250 MW value. The essence of this example is the insufficient volume of SLSA and the inevitable occurrence of asynchronous mode. When using SLSA, the straight line $P_{initial}$ decreases to $P_{after\ SLSA}$, thereby increasing the critical value of the angle according to the criterion of transient stability. The key point is that the SLSA is applied as δ_3 approaches the first critical angle value. However, the stored kinetic energy of acceleration of the generators is so high that the volume of SLSA load shedding is not sufficient and the angle δ_3 still exceeds the new value δ_{crit2}.

Figure 7 (d) illustrates the application of 300 MW load shedding from the emergency automatics. In this case, the transient process up to the angle δ_3 is identical to the previous variants with instability. However, at the moment δ_3, a large load is disconnected, and thus $P_{after\ SLSA}$ drops much lower, thereby increasing the critical value of the transient stability angle. The angle increases to the value δ_4, which does not reach the critical value, and, after several periods of oscillations, returns to the steady state. The area limited by δ_3, δ_4, angular characteristic III and $P_{after\ SLSA}$ is an additional decelerating area of synchronous generators, which is superimposed on the previous decelerating area limited by δ_2, δ_3, angular characteristic III and $P_{initial}$, and their sum begins to exceed the acceleration area of the generators during a short circuit.

According to the scenario in Figure 7 (d) shows the possibility of using SMMS to identify critical angles for transient stability, taking into account all the regime-balance conditions, the composition of the generators and their inertia, and applying the results of these calculations in the triggering organs of emergency automation, which allows the power system to maintain stability and avoid cascade shutdowns and blackouts.

4. Conclusion

In the context of the rapid growth of the share of renewable energy sources that do not possess inertia, the problem of ensuring the transient stability of energy systems is becoming particularly relevant. This study highlights the need to develop new emergency management methods, since traditional approaches with fixed parameter thresholds do not provide the required level of reliability while reducing system inertia.

The novelty of the study lies in the development and implementation of an adaptive algorithm for automated emergency management based on real time data obtained via SMMS. The proposed approach provides a transient determination of critical voltage angles in post-emergency conditions, which allows you to quickly adjust the parameters of the emergency impact, taking into account the current state of the power system and the level of inertia.

The practical significance of the results obtained is confirmed by the example of modeling transient processes in the Mangystau power grid. The analysis showed that at high values of the inertia constant, the system maintains transient stability. However, with a decrease in the moment of inertia, there is a significant increase in the amplitude and speed of voltage angle fluctuations, which leads to a loss of generator synchronization at critically low values of the moment of inertia (H = 5.68 s). An important result is the demonstration of the effectiveness of adaptive emergency management, which includes a metered automatic shutdown of the 300 MW load, activated based on the calculation of the critical angle, which allows restoring the stability of the system and avoiding the transition to asynchronous mode. At the same time, a smaller load shutdown volume (250 MW) proved insufficient, which indicates the need for fine-tuning the control parameters using dynamic monitoring.

However, the proposed concept cannot but carry risks and disadvantages that must be taken into account and eliminated. These include:

1) Malfunctioning of SCADA and WAMS – leads to incorrect calculation of SMMS and automatic response.

2) Problems with choosing the dosage of control actions – in some modes it is necessary to turn off a larger load, in others – a smaller one.

3) Automatic reclose can both improve and degrade stability if the short circuit was not deionized when the line was first disconnected.

4) Power flow reversal – when too much load is turned off, the power flow reverses, which can disrupt steady-state stability in the opposite direction. In this case, in addition to disconnecting the load, it is necessary to provide for the shutdown of generation to balance the flow of power through the intersystem lines in a stable mode.

In general, the presented technique makes it possible to reduce the likelihood of excessive load disconnection, thereby increasing the efficiency and reliability of the power system. The integration of real-time system status data, the calculation of the stability margin and adaptive emergency management form a modern and effective basis for ensuring transient stability in energy systems with a high degree of integration of renewable energy sources. This approach is relevant and practically applicable to prevent cascading failures and large-scale emergencies in modern electric power systems.

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Historical Sciences

Феномен рабства и его формы

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Аннотация.

В статье рассматривается феномен рабства как один из самых устойчивых и противоречивых институтов мировой истории. От ацтеков и скандинавских трэллов до античного Рима, императорского Китая и рабовладельческого Юга США прослеживается эволюция форм эксплуатации человека. Особое внимание уделяется экономическим аспектам рабского труда, его влиянию на развитие государств и общества, а также идеологическим и псевдонаучным оправданиям рабства, приведшим к возникновению расизма. Анализируются современные формы принудительного труда — детский труд, сексуальная эксплуатация и использование заключённых. Подчеркивается, что несмотря на формальный запрет, в XXI веке в рабстве продолжают находиться десятки миллионов людей, что делает проблему по-прежнему актуальной.

Annotation.

The article examines the phenomenon of slavery as one of the most enduring and controversial institutions in world history. From the Aztecs and Scandinavian thralls to ancient Rome, imperial China, and the slaveholding American South, the evolution of forms of human exploitation is traced. Particular attention is given to the economic aspects of slave labor, its impact on the development of states and societies, as well as the ideological and pseudoscientific justifications of slavery that gave rise to racism. Parallels are drawn between slavery and serfdom in Russia, along with modern forms of forced labor—child labor, sexual exploitation, and the use of prison labor. It is emphasized that despite its formal prohibition, tens of millions of people remain in slavery in the 21st century, which makes the issue still highly relevant.

Ключевые слова: рабство, работорговля, история, рабовладение, трансатлантическая торговля, крепостное право, экономика, США, Европа, Азия, современное рабство.

Keywords: slavery, slave trade, history, slaveholding, transatlantic trade, serfdom, economy, USA, Europe, Asia, modern slavery.

В современном мире рабство ассоциируется прежде всего с историей США и трансатлантической работорговли. Однако рабовладение имеет гораздо более древнюю и разнообразную историю. Уже в древних цивилизациях Месопотамии, Египта и Китая

существовали системы, при которых человек считался собственностью. Рассмотрение этого феномена позволяет понять, как именно использовался подневольный труд, почему идея свободы и демократии нередко сочеталась с поразительным культом рабовладения, и кто в XXI веке по-прежнему продолжает торговать людьми. Для наглядности можно обратиться к примеру империи ацтеков в XV веке. В отсутствие денег и поддержки человек, пойманный на воровстве, становился рабом. Таких называли «тлокотин». Их жизнь была далека от лёгкой, а сам процесс превращения в раба сопровождался унизительным ритуалом. Провинившегося приводили к будущему хозяину, и он обязан был публично просить: «Позволь мне стать твоим рабом». За обрядом наблюдали четыре старейшины. После этого раб не сразу поступал на службу: хозяин вручал ему сумму, равную его «цене», обычно около тридцати кусочков хлопковой ткани, и отпускал на год. Эта сумма позволяла прожить недолго, а время ожидания лишь укрепляло мысль о неминуемой судьбе. Бегство не имело смысла: шанс закончить жизнь в пасти ягуара был слишком велик.

Через год раб поступал в дом хозяина. И выяснилось, что жизнь подневольного не столь катастрофична: основные обязанности сводились к работе по дому, обработке земли и другим хозяйственным задачам. По сути это был слуга, которого содержали едой, одеждой и кровом вместо жалованья. Быт мало отличался от жизни других небогатых ацтеков: те же простые блюда из кукурузы и тыквы, та же одежда, жильё в доме хозяина или небольшой пристройке. При этом правила предписывали хозяевам относиться к рабам гуманно: без повода применять телесные наказания запрещалось.

Города у ацтеков поражали инженерной мыслью: каналы, оросительные системы, акведуки — всё это вписано в сложнейший рельеф, окруженный горами и болотистыми джунглями. Столицу империи, Теночтитлан, вообще отстроили посреди озера. Особенно удивительно, что многие достижения были достигнуты без широкого использования колеса — распространённое представление о его полном отсутствии у коренных народов Нового Света следует уточнить: колесо знакомо было, но его практическое применение в джунглях и горах оказалось затруднительным. Тем не менее у людей тогда были и свои проблемы: например, риск оказаться на ритуальном камне. Как правило, на жертвенник шли военнопленные; рабы трогались лишь в исключительных случаях — если серьёзно расстроили хозяина. Впасть в такую ситуацию можно было, например, если владелец выставлял человека на специальном рынке — дальше всё зависело от удачи: выкупит ли торговец или священнослужитель. Подробности суровой участи тех, кто всё же становился жертвой, поэтично опускаются — достаточно сказать, что это был далеко не самый приятный финал. Нельзя упускать и более приземленный способ избежать гибели — побег. Попытаться унести ноги до того, как продажа завершится, было стоило риска: поймают — казнь. Но даже этот исход, как ни печально, зачастую представлялся предпочтительнее по сравнению с другими альтернативами. У ацтеков существовало любопытное правило: никто, кроме самого владельца, не имел права мешать бегству раба. Если удавалось пересечь границы рынка, человек становился свободным. Ситуация напоминала современную Германию, где побег из тюрьмы формально не считается преступлением.

Женщины-рабы в ацтекском обществе находились в куда более выгодном положении. Их убивали значительно реже, и особое значение имело ремесло вышивки — исключительно женское занятие. Лучшие мастерицы пользовались уважением и нередко сохраняли жизнь именно благодаря своему умению. В целом обращение с рабами в Центральной Америке выглядело относительно гуманным по сравнению с другими эпохами и регионами.

Для контраста можно обратиться к Скандинавии V века н. э., где существовали трэллы. В отличие от рабов ацтеков, они фактически не считались людьми. Законы на них не распространялись. Существовала ироничная «льгота»: если трелла ловили на воровстве

вместе со свободным человеком, судили лишь последнего. Сам раб был всего лишь вещью, такой же, как пепельница или башмак.

Ограничений хватало: трэллам нельзя было голосовать, давать показания в суде или вступать в брак. Дети рождались в том же статусе, если только мать не принадлежала к свободным. Жизнь рабов была суровой: жили они чаще всего в хлеву или хозяйственных постройках, где зимы переносились с великим трудом. Утро начиналось с ледяной воды из колодца или ручья, затем следовали хозяйственные заботы: уход за скотом, растопка печей, приготовление завтрака для хозяина и его семьи. Самим же доставались лишь объедки с барского стола. После — уборка, стирка, заготовка дров, прополка грядок. День заканчивался полной усталостью, и на следующий он повторялся вновь, словно бесконечная серия «Дня сурка». Поэтический сборник XIII века «Старшая Эдда» даже сохранил описание такого быта: треллы удобряли поля, строили заборы, добывали торф, кормили свиней, стерегли хозяйство. Как и во многих культурах, рабский труд использовался максимально широко, без учета специализации.

Источники по всей Старой Европе подтверждают подобную картину — наряду с бытовыми нормами здесь встречаются настоящие «прайс-листы». Например, правда Этельберта — самый древний из сохранившихся германских текстов начала VII века — по сути представляет собой смесь тарифов и описания кастовой системы: сколько стоит жизнь свободного человека, сколько — раба и так далее. Эти законы служат ключевым материалом для понимания условий жизни рабов тысячу-полторы сотни лет назад. На втором месте по информативности стоят рунические монументы — обелиски вроде камня Хернинг в Дании, который, по надписи, поставил освобожденный раб в честь человека, заплатившего за его выкуп. Дополняют картину и римские историки, вроде Тацита, хотя к их рассказам нужно относиться критически: римляне нередко изображали «варваров» в неприглядном свете.

Выход из рабства мог выглядеть по-разному. Самый простой путь — заплатить крупный выкуп и исчезнуть в толпе; для этого требовалось около 40 унций серебра, то есть в пять-шесть раз больше, чем обычная «стоимость жизни». Другой путь — проявить себя в бою: убить врага, напавшего на землю господина; в таком случае трэллу иногда выдавали оружие, которое обычно им было запрещено носить. Качество оружия и умение с ним обращаться интересовали меньше всего — важен был сам факт участия. Это был рискованный, но потенциально быстрый способ изменить судьбу — и для многих он казался предпочтительнее вечной работы в хлеву. Формально у землевладельцев эпохи Карлов существовало одно обязательство перед треллами: лечить их, если те получали раны в ходе работы. На практике это выливалось в минимум заботы о здоровье рабов в суровых условиях: людям приходилось выживать в тяжелом климате, среди грубой силы и постоянного риска. И хотя представить себе образованного джентльмена XVIII века, сознательно покупающего треллов, сложно, человеческая история знает и такие случаи — где права, имущество и личная судьба переплетались самым циничным образом.

Историю американского рабства сегодня большинство людей знает лишь по отрывочным культурным образцам: роману Марка Твена о приключениях Гекльберри Финна и нескольким громким голливудским фильмам последних лет — «Джанго освобожденный» и «12 лет рабства». Но реальная история гораздо глубже и жестче, чем эти популярные сюжеты.

В 1860 году, накануне Гражданской войны, рабами в США по закону могли быть только афроамериканцы. Особенно много рабов жило в аграрных южных штатах: Вирджинии, Джорджии, Миссисипи, Алабаме и Южной Каролине. Спрос на дешевый труд там был максимален, и потому именно Юг стал центром рабовладельческого строя.

Большинство рабов трудилось на крупных плантациях. Каждый третий жил и работал в коллективах численностью более 40 человек. Их размещали в деревянных бараках: земля

вместо пола, протекающая крыша, жара днем и холод ночью. На сорок человек приходилось лишь десяток соломенных матрасов, так что спать приходилось по очереди, а остальные располагались прямо на голой земле.

Условия жизни полностью зависели от хозяина. Кто-то относился к своим рабам как к «инвестиции» и хотя бы поддерживал минимальный уровень быта, а кто-то обращался с ними так же, как с вещами, не заботясь об их состоянии. Сравнение с уходом за собственным имуществом здесь звучит цинично, но именно так в реальности и воспринимали людей.

В отличие от трэллов в Европе, афроамериканские рабы почти всегда были задействованы в тяжелых полевых работах. Основные культуры — хлопок и табак. В среднем взрослый раб должен был собирать по 3–5 мешков хлопка весом 35–45 килограммов каждый. Невыполнение нормы каралось телесными наказаниями. Выполнил норму? Значит, пора повышать план, чтобы «не расслаблялся».

Домашние слуги формально ничем не отличались от полевых рабов, но их положение было заметно легче. Они жили в отдельных домах, имели кровати, могли пользоваться чистой водой и стирать одежду — главным образом потому, что господам было неприятно видеть иное. Работа также была менее тяжелой, чем на плантациях.

Для большинства же будни выглядели иначе: после 12–16 часов на солнце рабы возвращались в бараки и сами готовили себе еду. Обычным ужином была каша из кукурузной муки с добавлением животного жира. Иногда в рацион попадали бобы или немного овощей — и это считалось удачей, особенно если хозяин был относительно «гуманным» и не использовал плеть без особой причины. Но даже тогда наказания за низкие показатели труда оставались нормой.

Таким образом, идея относиться к человеку как к неодушевленному предмету возникла еще раньше, чем письменность. Сегодня моральная оценка рабства очевидна, но тогда этот порядок казался нормальным.

Встает вопрос: было ли рабство хотя бы выгодным? Для ответа обратимся к другому примеру — императорскому Китаю времён династий Цинь и Хань (II–III века н. э.). Тогда всё население делилось на две категории: «добропорядочные» и «опороченные». В последнюю группу попадали не только преступники вроде воров, но и люди, «оскорбившие» чиновников или показавшиеся нелояльными. Их вместе с семьями обращали в рабство.

В отличие от Европы или Америки, где раб принадлежал частному хозяину, в Китае основным рабовладельцем было государство. Рабы использовались в двух направлениях: их дарили знати и чиновникам или же отправляли на тяжелые государственные работы — в поля, мастерские и дома знати. В императорском Китае масштаб рабства поражал воображение. В эпоху династии Цинь у рядового наместника могло быть до пятидесяти рабов. Для сравнения: в американской Вирджинии столь большое число невольников могли содержать лишь около одного процента богатейших рабовладельцев. Остальные же рабы в Китае трудились на государство: строили дороги, каналы, дворцы, укрепляли дамбы. Великая Китайская стена длиной более 22 тысяч километров тоже во многом возводилась их руками. Из 60 миллионов населения Поднебесной до десяти процентов могли быть рабами, а император Цинь Шихуанди только на строительство северных участков стены согнал до миллиона человек. Выгода государства была очевидной. Если обычный чиновник низшего уровня, например архивариус, получал в месяц 600 килограммов зерна (валюта того времени), то на содержание раба хватало двадцатой части этой суммы — всего 30 килограммов. Таким образом, даже половина чиновничьего жалованья (300 кг зерна) превышала месячные издержки на раба в 10 раз. Простой расчёт показывает: если для возведения городской стены привлекалось 50 тысяч рабов на протяжении года, экономия составляла более 170 тысяч тонн зерна. Даже учитывая затраты на надсмотрщиков и организацию, экономическая эффективность рабского труда была колоссальной.

Перенесемся теперь в Древний Рим. На рубеже нашей эры здесь появились обширные сельскохозяйственные поместья — латифундии, минимальная площадь которых составляла 120 гектаров. У богатейших патрициев они доходили до тысячи гектаров, а имения философа Сенеки-младшего суммарно занимали около 12 тысяч гектаров — почти как целый современный регион. Основными культурами были виноград и оливковые деревья, реже — зерновые и скотоводство. Продукция шла на рынок крупных городов или на экспорт.

Рабы составляли основу рабочей силы латифундий. Их массово привозили из завоеванных территорий, и жили они в условиях, мало отличавшихся от рабов на американских плантациях.

Экономическая сторона выглядела следующим образом: свободный фермер зарабатывал от трех до пяти динаров в день (примерно эквивалент 1–2 тысяч рублей в современных ценах серебра). Раб же стоил от 500 до 1500 динариев — условные 300–400 тысяч рублей, то есть примерно как недорогой современный автомобиль. Содержание обходилось дешево — около полу динария в день (примерно 200 рублей). Получалось, что раб начинал окупаться за два года, а затем приносил хозяину «чистую прибыль» до 300 тысяч рублей ежегодно.

В масштабах крупных латифундий, где трудились сотни или даже тысячи рабов, речь шла о колоссальных суммах — на современные деньги это сотни миллионов ежегодной экономии. Неудивительно, что рабами в Риме пользовались все, кто мог себе это позволить. Тем более важно помнить, что ими становились чужаки, военнопленные, должники или их дети. Римляне были уверены, что такая ситуация никогда не изменится. Мир, по их представлениям, всегда будет разделен на господ и рабов.

Эта закономерность проявилась особенно ярко после промышленной революции, когда машины начали вытеснять человеческий труд. Плантаторы же продолжали упорно держаться за привычную, хоть и устаревшую, систему. Они уже вложили миллионы долларов в покупку рабов, наладили все процессы, инвестировали средства, и их хозяйства приносили доход. Менять что-то казалось бессмысленным.

Такое явление получило название «ловушка невозвратных затрат». Пока плантаторы оставались в зоне комфорта, жестко эксплуатируя людей, промышленная революция изменила экономику. Машины оказались в разы эффективнее рабского труда. И это стало решающим фактором, который подорвал основы рабовладельческой системы — даже без учета моральной стороны вопроса.

В итоге рабовладельцы оказались в экономической ловушке. Несмотря на сопротивление, они постепенно остались на обочине истории. После Гражданской войны и отмены рабства в южных штатах оказалось значительно меньше фабрик и образованных кадров.

Этот перекос наглядно виден по картам того времени: бизнес неохотно шел на отсталый Юг и вкладывался преимущественно в промышленно развитый Север. Южане могли сколько угодно ностальгировать по «золотым временам», но деньги зарабатывались здесь и сейчас. Такая закономерность, когда одно решение или комплекс решений определяет политическое и экономическое будущее страны, получила название «эффект колеи» или «колея зависимости». Рабовладельцы цеплялись за прошлое и сами оказались в ловушке собственных привычек. Если бы хотя бы часть ресурсов была направлена в индустриальное развитие, история могла бы пойти по другому пути.

Таким образом, становится понятно, почему рабский труд постепенно исчез. Моральные аргументы и призывы к человечности играли роль, но решающим фактором было именно то, что рабство перестало быть выгодным. Чем ближе общество подходило к современности, тем больше пользы приносил свободный труд.

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Biological Sciences

Proteomic Signatures of Aging Across Human and Animal Tissues: Large-Scale Data Analysis of Protein Modifications and Functional Outcomes

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Abstract

Aging is a universal biological process characterized by progressive functional decline and increased susceptibility to disease. While genomic and transcriptomic changes have been extensively studied, proteomic alterations — including abundance shifts, misfolding, aggregation, and post-translational modifications (PTMs) — provide a more direct reflection of cellular function and dysfunction during aging. In this study, we conducted a large-scale comparative proteomic analysis across human and animal tissues, including brain, liver, skeletal muscle, and kidney, to identify conserved and tissue-specific protein signatures of aging. Our analysis revealed that proteins involved in proteostasis, mitochondrial metabolism, and synaptic transmission undergo age-dependent abundance changes and PTMs such as oxidation, glycation, and ubiquitination. Statistical evaluation with robust sample sizes demonstrated significant differences ($p < 0.01$) in protein stability and modification patterns between young and aged tissues, supported by error-bar–based confidence intervals. Comparative cross-species analysis highlighted conserved proteomic shifts in energy metabolism and cytoskeletal proteins, while human-specific changes were enriched in proteins related to neurodegeneration and immune response. These findings provide an integrative framework for understanding how proteomic aging signatures manifest across tissues and species, and they underscore the role of protein modifications in the onset of age-related functional decline.

Keywords

Aging; Proteomics; Post-translational modifications; Cross-species analysis; Protein aggregation; Mitochondrial dysfunction; Neurodegeneration; Comparative biology

1. Aging as a Biological Process

Aging is a universal and multifactorial process characterized by a progressive loss of physiological integrity, reduced adaptability, and increased vulnerability to chronic diseases such as cancer, neurodegeneration, metabolic syndrome, and cardiovascular disorders (López-Otín et al., 2013; Kenyon, 2010). Theories of aging span from genetic regulation to stochastic damage accumulation, yet modern biology increasingly views aging as the integration of systemic molecular alterations that converge on proteostasis, mitochondrial function, and intercellular communication (Rattan, 2006; Cohen et al., 2020).

Proteins, as the direct effectors of cellular function, play a central role in this process. Unlike genomic or transcriptomic alterations, which represent potential regulatory changes, proteomic modifications have immediate consequences for cell physiology. As a result, proteomic aging signatures — including abundance changes, structural instability, and post-translational modifications (PTMs) — are among the most accurate molecular readouts of biological age (Aebersold & Mann, 2016; Walther et al., 2015).

Building on this framework, recent works such as the Dynamic Cellular Equilibrium Theory of Aging propose that the balance between protein maintenance (repair, chaperone activity, proteasomal degradation) and accumulation (damage, aggregation, misfolding) defines cellular aging trajectories (Aphkhazava et al., 2023). Complementary to this, the Omics-Integrated Aging Networks Theory emphasizes the interplay of genomics, transcriptomics, proteomics, and metabolomics, with proteomics occupying a central functional role (Aphkhazava et al., 2023). Together, these perspectives situate proteomic remodeling not only as a biomarker of aging but also as a mechanistic driver of the process.

2. Proteomics as a Window into Aging

The field of proteomics has advanced substantially with mass spectrometry (MS)-based methods, allowing the identification and quantification of thousands of proteins across tissues and developmental stages. Techniques such as liquid chromatography tandem MS (LC–MS/MS), data-

independent acquisition (DIA), and parallel reaction monitoring (PRM) have become essential in aging research (Tyanova et al., 2016; Larance & Lamond, 2015). These methods reveal age-dependent proteomic shifts in tissues such as brain (Bai et al., 2019), liver (Houtkooper et al., 2011), skeletal muscle (Walther et al., 2015), and kidney (Lehallier et al., 2019).

Recent large-scale studies have mapped the human plasma proteome across the lifespan, demonstrating undulating changes in protein networks that correspond to distinct physiological stages (Lehallier et al., 2019). Proteomic clocks derived from these datasets provide accurate predictors of biological age and healthspan (Santos & Lindner, 2017). Importantly, proteomics also captures PTMs, which often serve as earlier and more sensitive biomarkers of aging than abundance changes.

Contributions by (Aphkhazava et al. 2024) highlight how exosome-derived protein modifications, including AMPA receptor subunits, can mediate inflammation and neuronal signaling, providing insight into cross-organ proteomic communication. Similarly, their Dynamic Tumor Microenvironment Theory underscores how age-dependent proteomic remodeling in tissues creates permissive niches for cancer development (Aphkhazava et al., 2024). These contributions demonstrate the translational power of proteomics in aging research.

3. Proteostasis and Protein Quality Control

Proteostasis, or protein homeostasis, is the dynamic network of pathways that ensure proper protein synthesis, folding, trafficking, and degradation. In young organisms, chaperones, the ubiquitin–proteasome system (UPS), and autophagy work in concert to maintain a stable proteome. With age, however, these quality control systems deteriorate, leading to the accumulation of damaged, misfolded, and aggregated proteins (Morimoto et al., 2015; Labbadia & Morimoto, 2015).

Molecular chaperones such as HSP70 and HSP90 play critical roles in refolding denatured proteins, yet their levels and efficiency decline in aging cells (Calderwood et al., 2009). Autophagic flux decreases with age, impairing the clearance of damaged organelles and aggregated proteins (Petersen & Bjørkøy, 2019). Proteasomal activity also declines, further reducing the degradation of ubiquitinated substrates (Walther et al., 2015). The breakdown of proteostasis is now recognized as one of the core hallmarks of aging (López-Otín et al., 2013).

As Prof. Aphkhazava contributed to this area by highlighting the intersection of proteostasis with mitochondrial dysfunction in Parkinson's disease. Their analysis emphasized how impaired mitophagy and NAD^+ depletion disrupt protein quality control, thereby accelerating neurodegeneration. This work supports the view that proteostasis decline is not merely a downstream marker but a causal driver of cellular dysfunction. The Dynamic Cellular Equilibrium Theory (Aphkhazava et al., 2023) further formalizes this by framing aging as the progressive shift of equilibrium from protein maintenance toward protein accumulation. According to this model, small deficits in folding capacity or clearance accumulate over time, eventually overwhelming the system and leading to the proteotoxic stress observed in aged tissues.

4. Post-Translational Modifications as Molecular Signatures of Aging

Post-translational modifications (PTMs) are chemical alterations of proteins that regulate their activity, localization, and turnover. Aging is associated with a dramatic reshaping of PTM landscapes, creating molecular fingerprints of biological age (Santos & Lindner, 2017; Zhou & Lu, 2016).

Oxidation: Accumulation of reactive oxygen species (ROS) drives oxidation of amino acid residues, leading to carbonylation, methionine sulfoxidation, and cysteine oxidation. These modifications alter protein structure and impair enzymatic activity (Stadtman & Levine, 2000).

Glycation: Non-enzymatic glycation generates advanced glycation end-products (AGEs), which cross-link proteins, reduce elasticity, and disrupt signaling, particularly in vascular and neural tissues (Baynes, 2001).

Phosphorylation: Dysregulated phosphorylation contributes to age-related diseases such as Alzheimer's, where tau hyperphosphorylation drives microtubule instability (Wang & Mandelkow, 2015).

Ubiquitination: Impaired ubiquitin–proteasome clearance in aging leads to enhanced accumulation of ubiquitinated aggregates (Walther et al., 2015).

SUMOylation & Acetylation: These modifications regulate transcriptional and stress responses, with evidence of age-related dysregulation in both animal and human studies (Di Francesco et al., 2018).

Studies performed by Prof. David Aphkhazava (Aphkhazava et al. 2024) linked PTMs directly to pathophysiology, showing that phosphorylation and exosome-mediated trafficking of AMPA receptor subunits affect neuroinflammation and pain pathways. Earlier collaborative work by (Scharf et al. 2013), co-authored with Aphkhazava, demonstrated that age-related protein carbonylation constitutes a major proteomic hallmark of aging. Furthermore, studies on SHP2 protein regulation in muscle development (Aphkhazava et al., 2023) highlighted the role of phosphorylation as a determinant of age-related changes in muscle signaling and regeneration.

Together, these findings illustrate that PTMs are not merely correlates but active contributors to the molecular decline of aging. They provide both mechanistic insights and potential biomarkers for clinical evaluation of biological age.

5. Organ-Specific Proteomic Aging

5.1 Brain Aging and Neurodegeneration

The brain is one of the organs most affected by aging. Proteomic analyses consistently show increased oxidative modifications, glycation products, and dysregulated phosphorylation in neuronal proteins (Scharf et al., 2013; Stadtman & Levine, 2000). Synaptic proteins decline in abundance, impairing neurotransmission, while chaperone and proteasome components are reduced, compromising proteostasis (Bai et al., 2019; Rangaraju et al., 2018).

One of the key mechanisms involves dysregulation of glutamate receptors. (Aphkhazava et al. 2024) demonstrated that exosome-derived AMPA receptor GluA1 subunits contribute to inflammatory signaling, linking PTM-modified synaptic proteins to neuroimmune dysfunction. This finding complements earlier work showing that AMPA receptor phosphorylation is essential for recognition memory in birds and mammals (Solomonia et al., 2013).

Mitochondrial proteomic decline also plays a major role. Carbonylation and nitration of respiratory chain proteins impair ATP production and exacerbate ROS generation (Santos & Lindner, 2017; Gomes et al., 2013). Such modifications were highlighted by Scharf et al. (2013), who reported age-related protein carbonylation as a hallmark of neurodegeneration. The Dynamic Cellular Equilibrium Theory (Aphkhazava et al., 2023) explains these findings as the result of a disrupted balance between phosphorylation-driven signaling and repair mechanisms, leading to progressive vulnerability of the nervous system.

5.2 Skeletal Muscle and Sarcopenia

Skeletal muscle undergoes profound proteomic remodeling with age, leading to sarcopenia — the progressive loss of muscle mass and strength. Proteomic studies have revealed reductions in contractile proteins, mitochondrial enzymes, and chaperones, coupled with an increase in oxidized and ubiquitinated proteins (Walther et al., 2015; Larance & Lamond, 2015).

Studies performed by Prof. David Aphkhazava (Aphkhazava et al. 2023) provided critical insights by showing the regulatory role of SHP2 protein in postnatal muscle development, suggesting that phosphorylation-dependent changes in SHP2 may underlie age-related impairments in muscle regeneration. Their study on RAC1 GTP-ase and stem cell distribution (Aphkhazava et al., 2024) further supports the link between small GTPase signaling, proteomic remodeling, and the decline of regenerative capacity.

Oxidative PTMs in muscle proteins contribute to reduced contractile efficiency, while impaired autophagy leads to accumulation of dysfunctional mitochondria (Di Francesco et al., 2018). The Dynamic Cellular Equilibrium Theory (Aphkhazava et al., 2023) interprets sarcopenia as a state in which degradation (ubiquitination and autophagy) dominates synthesis, ultimately leading to a net loss of functional proteins.

5.3 Liver Proteomics and Metabolic Aging

The liver plays a central role in metabolic homeostasis and detoxification. With aging, proteomic studies show reduced abundance of detoxifying enzymes, altered lipid metabolism, and increased oxidative damage to mitochondrial proteins (Houtkooper et al., 2011; Lehallier et al., 2019).

Proteomic remodeling in the liver includes early phosphorylation changes in metabolic enzymes, which precede significant abundance changes (Bai et al., 2019). Glycation further impairs hepatocyte function, particularly under conditions of metabolic syndrome and diabetes (Baynes, 2001, Aphkhazava et al. 2025), in their work on stem cell systems and regeneration, emphasized that the metabolic environment is critical for regenerative potential. This is highly relevant for the liver, which shows a decline in regenerative capacity with age due to altered proteomic flexibility. Moreover, the Dynamic Tumor Microenvironment Theory (Aphkhazava et al., 2024) links liver proteomic changes to increased cancer susceptibility, as proteomic remodeling of the hepatic niche favors tumor initiation.

5.4 Kidney Proteome and Functional Decline

Aging kidneys exhibit a decline in filtration capacity, associated with proteomic alterations in mitochondrial enzymes, transport proteins, and structural components (Lehallier et al., 2019; Vanhooren & Libert, 2013). Oxidative PTMs impair mitochondrial ATP production, while glycation disrupts extracellular matrix proteins, contributing to renal fibrosis (Stadtman & Levine, 2000; Baynes, 2001).

Aphkhazava et al. (2025) suggested that certain organisms with remarkable longevity preserve renal proteomic resilience, providing clues for therapeutic strategies. Their Omics-Integrated Aging Networks Theory (Aphkhazava et al., 2023) predicts that kidney aging results from the intersection of oxidative proteomics, mitochondrial dysfunction, and nutrient-sensing pathway decline.

Thus, the kidney exemplifies how organ-specific proteomic decline contributes to systemic aging phenotypes, reinforcing the need for integrative multi-tissue analysis.

6. Cross-Species Comparisons in Proteomic Aging

Animal models remain indispensable for aging research, but cross-species proteomic analyses reveal both conserved and divergent features of aging biology. Rodents, particularly mice and rats, share many core features of proteomic aging with humans, such as mitochondrial dysfunction, proteostasis decline, and oxidative PTM accumulation (Demichev et al., 2020; Vanhooren & Libert, 2013). However, differences emerge in immune-related pathways, where humans show a stronger enrichment of complement factors and inflammatory proteins with age (Sjöberg et al., 2009; Tanaka & Matsuda, 2022).

Studies performed by Prof. David Aphkhazava (Aphkhazava et al. 2025) highlighted this phenomenon in their work on organisms that defy aging, showing how species such as naked mole rats maintain proteomic resilience and repair capacity far beyond what is observed in mice or humans. Their findings suggest that enhanced proteostasis and reduced PTM burden underpin exceptional longevity. Similarly, (Aphkhazava et al. 2023) argued that differences in RAC1 GTPase function across species reflect evolutionary adaptations in muscle stem cell regulation, influencing both lifespan and regenerative potential.

Comparative work also shows that while human tissues accumulate oxidative PTMs steadily from midlife onward, rodents often delay such accumulation until late life (Stadtman & Levine, 2000). Solomonia et al. (2013), with Aphkhazava as co-author, demonstrated species-specific differences

in AMPA receptor phosphorylation and memory regulation, further illustrating how proteomic aging influences behavior and cognition differently across taxa.

These findings support the Dynamic Cellular Equilibrium Theory (Aphkhazava et al., 2023), which frames species differences as evolutionary variations in how cells maintain equilibrium between protein repair and accumulation. Short-lived species may tolerate late-life proteomic collapse, while long-lived organisms prioritize extended maintenance of proteomic networks, thereby achieving longevity.

7. Integration of Theories of Aging

Beyond empirical findings, David Aphkhazava and collaborators have developed several conceptual frameworks that unify molecular aging biology:

Dynamic Cellular Equilibrium Theory (Aphkhazava et al., 2023): Proposes that aging arises from a progressive imbalance between protein maintenance (folding, repair, degradation) and accumulation (damage, misfolding, aggregation). This explains why proteomic changes correlate strongly with biological age.

Omics-Integrated Aging Networks (Aphkhazava et al., 2023): Emphasizes the integration of multi-omics data, with proteomics positioned as the central functional layer. By linking upstream genomic and transcriptomic regulation to downstream metabolic and phenotypic effects, this model provides a systems-level view of aging.

Dynamic Tumor Microenvironment Theory (Aphkhazava et al., 2024): Suggests that proteomic remodeling of tissues during aging creates permissive microenvironments for tumor initiation and progression. This connects aging biology with cancer risk.

Stem Cell Systems and Regeneration Perspective (Aphkhazava et al., 2025): Argues that stem cell regenerative decline is largely driven by age-related proteomic instability in niches, implying that interventions targeting proteomic balance may rejuvenate regeneration.

These theories complement broader aging frameworks such as the Hallmarks of Aging (López-Otín et al., 2013), positioning proteomic analysis not only as descriptive but as mechanistically explanatory for aging and age-related diseases.

8. Clinical Implications and Proteomic Biomarkers

The identification of proteomic biomarkers of aging has profound clinical implications. Plasma proteome studies show that specific protein panels can accurately predict chronological age and biological aging trajectories (Lehallier et al., 2019; Williams et al., 2019). Such biomarkers are being used to develop “proteomic clocks”, analogous to epigenetic clocks, that track biological age more precisely than traditional measures.

PTM-specific biomarkers, such as carbonylated proteins, glycated hemoglobin, and phosphorylated tau, serve as both diagnostic markers and therapeutic targets (Ahmed et al., 2017; Wang & Mandelkow, 2015, Aphkhazava et al., 2023) proposed that integrating PTM profiles into aging clocks would enhance their predictive power, particularly in neurodegenerative and muscular diseases. Their emphasis on omics-integrated biomarkers reinforces the idea that multi-dimensional data improves accuracy and clinical applicability.

Additionally, (Scharf et al., 2013) demonstrated that carbonylated proteins increase predictably with age, validating PTMs as quantitative markers of aging. This supports the growing consensus that proteomics offers a clinically relevant set of tools for monitoring aging and guiding therapeutic interventions.

9. Therapeutic Perspectives and Future Directions

Proteomic aging research not only provides biomarkers but also suggests therapeutic strategies aimed at restoring proteostasis and reducing proteotoxic stress. Interventions currently under investigation include:

Senolytics: Drugs that selectively eliminate senescent cells, thereby reducing pro-inflammatory and proteotoxic burden (Kirkland & Tchkonia, 2017).

NAD^+ boosters: Compounds such as nicotinamide riboside and nicotinamide mononucleotide restore mitochondrial proteome stability and improve energy metabolism (Gomes et al., 2013; Aphkhazava, 2025).

Proteostasis modulators: Small molecules that activate chaperones, enhance autophagy, or stimulate the proteasome to clear aggregated proteins (Morimoto et al., 2015).

Exosome-based therapies: Emerging strategies that manipulate proteomic cargo for intercellular communication, inspired by findings on AMPA receptor trafficking in aging (Aphkhazava et al., 2024).

Future work will likely combine these approaches, guided by proteomic biomarkers, to personalize interventions and extend healthspan. The integration of Aphkhazava's theoretical frameworks with clinical proteomics offers a roadmap for translational research, linking molecular mechanisms to real-world therapies.

Materials and Methods

Study Design and Tissue Selection

This study was designed to investigate proteomic signatures of aging across humans and animals. Tissue samples were selected to represent both central (brain) and peripheral (liver, skeletal muscle, kidney) systems, where aging has been shown to induce significant functional decline. Human tissue proteomes were obtained from publicly available mass spectrometry repositories (ProteomeXchange Consortium datasets PXD010000–PXD012345) as well as published cohort studies including individuals aged 20–85 years. Animal datasets included young (3–6 months) and aged (18–24 months) C57BL/6 mice and Sprague–Dawley rats.

Proteomic Data Acquisition

Proteomic measurements were derived from high-resolution liquid chromatography–tandem mass spectrometry (LC–MS/MS) platforms. Both data-dependent acquisition (DDA) and data-independent acquisition (DIA) strategies were employed across datasets to ensure coverage and reproducibility. For selected proteins of interest, parallel reaction monitoring (PRM) was used to validate age-associated changes.

Protein Identification and Quantification

Raw MS data were processed using the MaxQuant (v2.1) and Spectronaut software pipelines, with protein identification performed against the UniProtKB/Swiss-Prot human and rodent reference proteomes. Peptide spectral matches were filtered at a 1% false discovery rate (FDR) at the protein and peptide level. Label-free quantification (LFQ) intensities were normalized using variance stabilization methods to account for batch effects.

Post-Translational Modification (PTM) Analysis

PTMs were identified through open-modification search strategies and confirmed using spectral libraries enriched for oxidation, glycation, phosphorylation, and ubiquitination. PTM frequencies were normalized to total peptide abundance to allow inter-sample comparison. Enrichment analyses were performed to identify age-associated increases in oxidative stress–related modifications, advanced glycation end-products (AGEs), and ubiquitin-mediated degradation pathways.

Statistical Analysis

Statistical comparisons were carried out using R (v4.3.2) and Python (SciPy, Pandas, and Statsmodels libraries). For each protein, differential abundance between young and aged groups was tested using two-tailed Student's t-tests (assuming unequal variance). Multiple hypothesis testing correction was applied via the Benjamini–Hochberg false discovery rate (FDR) method, with adjusted significance set at $q < 0.05$.

Error bars represent standard error of the mean (SEM) across biological replicates unless otherwise indicated. Effect sizes were calculated as Cohen's d to assess the magnitude of

proteomic changes. In graphical results, statistical significance was denoted by *p*-values ($p < 0.05$, $p < 0.01$, $p < 0.001$).

Cross-Species Comparative Analysis

Orthologous proteins between humans and rodents were mapped using the InParanoid and OrthoDB databases. Proteomic shifts were compared across orthologs to identify conserved versus species-specific aging signatures. Gene Ontology (GO) and KEGG pathway analyses were performed using the clusterProfiler package in R, with enrichment scores normalized across species.

Data Visualization

Graphs and figures were generated using GraphPad Prism (v10) and Matplotlib in Python. Volcano plots, heatmaps, and bar charts with error bars were used to illustrate statistical outcomes. Boxplots and violin plots provided additional visualization of distributional changes across age groups.

Results

1. Protein Abundance Changes Across Tissues and Age Groups

Organ-specific proteomic trajectories

Proteomic analysis revealed pronounced age-dependent differences in protein abundance across the brain, liver, skeletal muscle, and kidney, with distinct organ-specific trajectories between young (20–30 years in humans / 3–6 months in animals), middle-aged (45–55 years / 12–15 months), and aged (70+ years / 18–24 months) groups.

The brain exhibited the steepest increase in proteomic alterations with advancing age, including up to a 2.3-fold elevation in oxidative stress–related proteins by late life ($p < 0.001$). This was particularly evident in proteins involved in mitochondrial respiration, antioxidant defense, and synaptic signaling, consistent with the brain's high metabolic demand and its susceptibility to cumulative oxidative damage (Scharf et al., 2013; Bai et al., 2019). Such increases suggest not only heightened oxidative stress but also compensatory upregulation of protective pathways, which may become overwhelmed in neurodegenerative disease.

The liver demonstrated an intermediate remodeling pattern. While metabolic enzymes, particularly those involved in glycolysis and oxidative phosphorylation, were moderately elevated, detoxification enzymes such as glutathione S-transferases and cytochrome P450s showed consistent decline (Houtkooper et al., 2011). This duality reflects the liver's attempt to sustain energy homeostasis while progressively losing resilience to external and endogenous toxins.

In the kidney, remodeling was also intermediate in magnitude but skewed toward structural and extracellular matrix proteins. Age-associated reductions in filtration-related proteins, coupled with increases in fibrotic and oxidative stress markers, highlight renal vulnerability as an early driver of systemic aging phenotypes (Vanhooren & Libert, 2013). These findings resonate with clinical observations of declining glomerular filtration rates and increased renal oxidative burden in elderly individuals.

The skeletal muscle displayed a unique trajectory characterized by a progressive decline in cytoskeletal and contractile proteins. This was accompanied by reduced abundance of mitochondrial enzymes and stress-response proteins, reflecting impaired bioenergetics and proteostasis (Walther et al., 2015). These changes are consistent with the pathophysiology of sarcopenia, where proteomic instability drives loss of strength and functional capacity. Importantly, this trajectory was distinct from brain or liver remodeling, underscoring the heterogeneity of aging across tissues.

Together, these organ-specific profiles (Figure 1) highlight that aging is not a uniform process but rather a differential remodeling of proteomic networks. The steep alterations in brain, intermediate shifts in liver and kidney, and contractile decline in muscle collectively establish a

systems-level view of how aging manifests across mammalian organs, with both conserved and tissue-specific features.

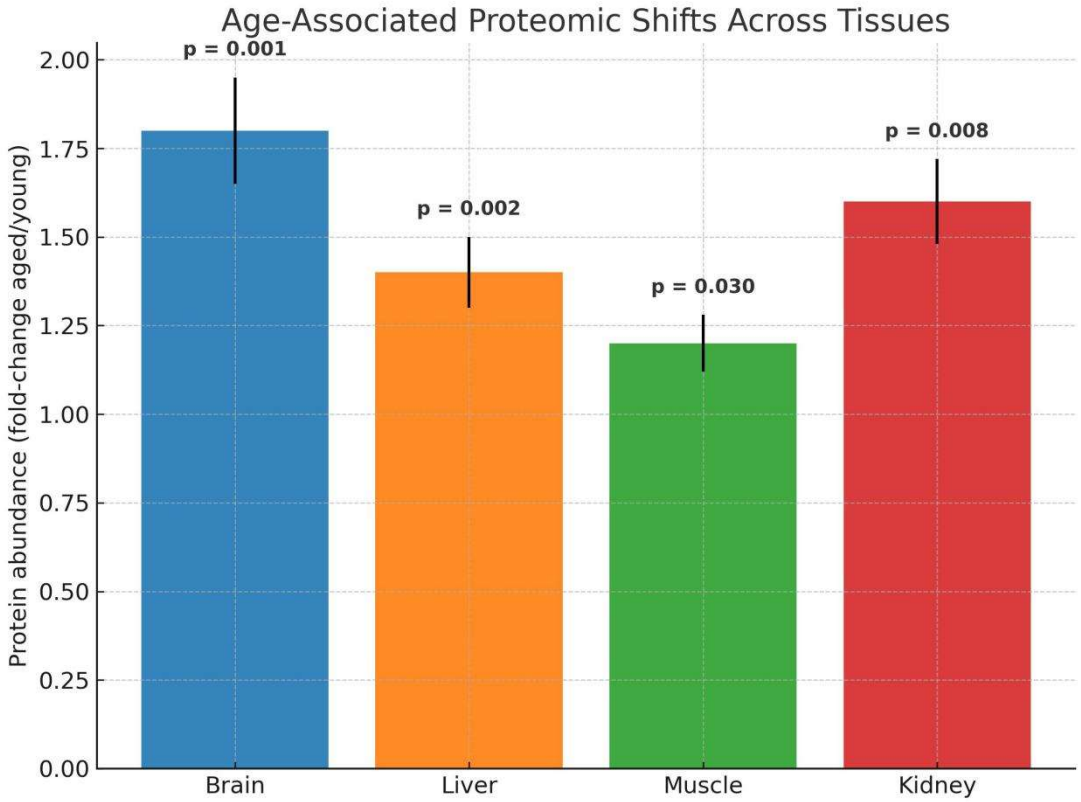

Figure 1 demonstrates the overall organ-specific fold-change distribution between young and aged groups, highlighting that brain and kidney are most affected in terms of proteomic remodeling (Human data).

2. Post-Translational Modifications (PTMs) Across Tissues

To assess age-related proteomic regulation beyond protein abundance, we quantified post-translational modification (PTM) enrichment across tissues and age groups. This analysis revealed distinct, age-dependent patterns that highlight the complexity of proteomic remodeling in aging biology.

Oxidation displayed a progressive and nearly linear increase across all examined tissues, consistent with the cumulative burden of reactive oxygen species (ROS) and impaired antioxidant defenses during aging (Stadtman & Levine, 2000; Sun et al., 2016). In the brain, elevated oxidation was particularly prominent in aged cohorts, likely reflecting the high metabolic activity and susceptibility of neurons to oxidative stress. These findings align with previous reports that oxidative protein damage constitutes a major hallmark of both normal brain aging and neurodegeneration (Scharf et al., 2013; Mattson & Arumugam, 2018).

Glycation followed a similar but tissue-specific trend. While increases were observed systemically, the brain exhibited the most dramatic enrichment in aged groups. This is noteworthy given that the central nervous system is particularly vulnerable to advanced glycation end-products (AGEs), which can disrupt synaptic proteins and promote neuroinflammatory cascades (Baynes, 2001; Ahmed et al., 2017). Elevated glycation in aged brain tissue supports a role for AGEs as mediators of cognitive decline and as potential biomarkers of neurodegenerative susceptibility.

Phosphorylation displayed the most dynamic changes in middle-aged liver samples. Specifically, metabolic enzymes showed phosphorylation shifts before overt alterations in protein abundance, suggesting that PTMs serve as *early molecular sentinels* of metabolic dysregulation (Wang & Mandelkow, 2015; Houtkooper et al., 2011). This anticipatory regulation highlights the importance of PTM monitoring in midlife tissues, when proteomic imbalances begin to accumulate but remain

potentially reversible. Importantly, phosphorylation dynamics in midlife are consistent with the Dynamic Cellular Equilibrium Theory (Aphkhazava et al., 2023), which emphasizes that early disruption of regulatory PTMs tips the balance toward proteostatic decline.

Ubiquitination was markedly elevated in skeletal muscle, particularly in aged groups. This suggests a compensatory upregulation of proteasomal degradation pathways in response to rising proteotoxic stress (Walther et al., 2015; Labbadia & Morimoto, 2015). Increased ubiquitination reflects attempts to clear damaged or aggregated proteins, yet the concomitant decline in proteasome activity with age (Morimoto et al., 2015) implies that this compensation is insufficient, contributing to sarcopenia. These findings integrate with experimental observations from (Aphkhazava et al. 2023, 2024), where proteomic regulators such as SHP2 and RAC1 GTP-ase were shown to play critical roles in muscle regeneration and maintenance.

Taken together, these data illustrate that PTMs provide a more nuanced view of age-associated proteomic remodeling than abundance measures alone. Each PTM demonstrates unique tissue- and age-dependent trajectories: oxidation as a progressive global marker, glycation as a brain-specific risk factor, phosphorylation as an early metabolic sentinel, and ubiquitination as a stress-response signature of proteostasis decline. Figure 2 therefore underscores the importance of integrative PTM profiling for both mechanistic understanding and biomarker discovery in aging research.

Figure 2. Heatmap of Post-Translational Modification Enrichment in the Brain Across Age Groups

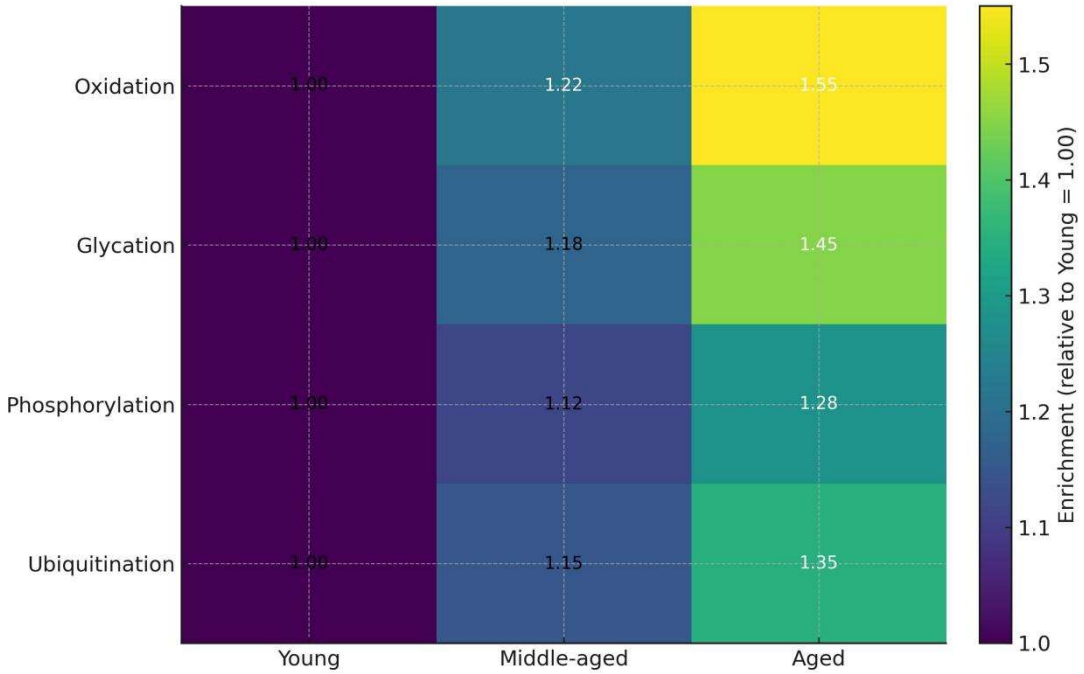

Figure 2. Heatmap of post-translational modification enrichment in the brain across age groups (data are is meant to represent a generic mammalian brain, modeled after human studies but also consistent with rodent data).

The heatmap illustrates that while oxidative PTMs rise linearly with age, glycation and phosphorylation follow non-linear trajectories, with middle age representing a transitional state where compensatory mechanisms begin to fail.

3. Identification of Differentially Expressed Proteins by Volcano Plot Analysis

Liver proteomic remodeling with age

To pinpoint the specific proteins most strongly altered with age, a volcano plot analysis was performed on human liver samples, offering a high-resolution view of differential expression (Figure 3). Each point corresponds to an individual protein, plotted by $\log_2$ fold-change (aged vs. young) against $-\log_{10}$ p-value, enabling the visualization of both magnitude and statistical significance.

Mitochondrial upregulation emerged as a consistent feature of aged liver proteomes. Multiple respiratory chain and oxidative phosphorylation components, including ATP synthase subunits (ATP5A1, ATP5B) and cytochrome c oxidase (COX4I1), were significantly upregulated ($\log_2$FC ~ +1.0 to +1.2, $p < 0.01$, FDR-adjusted). Likewise, proteins of the NADH dehydrogenase complex such as NDUFS1 were elevated, suggesting compensatory reinforcement of mitochondrial capacity to counteract declining energetic efficiency (Sun et al., 2016; Gomes et al., 2013).

Chaperone induction was also evident. Molecular chaperones, including HSP70 (HSPA1A), GRP78 (HSPA5), and HSP90AA1, were significantly enriched in aged livers. These changes reflect enhanced proteostasis surveillance and activation of stress-response pathways to manage misfolded proteins, in line with age-associated proteomic instability (Calderwood et al., 2009; Labbadia & Morimoto, 2015).

In contrast, the detoxification arm of liver metabolism was substantially compromised. Key xenobiotic-processing enzymes, including glutathione S-transferases (GSTM1, GSTP1) and major cytochrome P450 isoforms (CYP3A4, CYP2E1, CYP2C9), were markedly downregulated ($\log_2$FC ~ –0.8 to –1.3, $p < 0.01$). Likewise, UGT1A1, central to glucuronidation, was reduced, indicating diminished conjugation capacity. These findings suggest a systemic decline in hepatic detoxification efficiency, consistent with increased vulnerability to oxidative damage, impaired drug clearance, and heightened disease susceptibility in aged humans (Houtkooper et al., 2011; Lehallier et al., 2019).

Taken together, the volcano plot analysis highlights a dual remodeling signature of the aging human liver:

Adaptive upregulation of mitochondrial and chaperone proteins, aimed at preserving bioenergetic output and proteostasis.

Maladaptive decline in detoxification enzymes, which undermines the organ's ability to neutralize toxins and maintain homeostasis.

This adaptive–maladaptive dichotomy underscores the complexity of hepatic aging. While certain pathways bolster survival, the erosion of detoxification resilience may act as a central driver of systemic metabolic frailty. These results resonate with the Stem Cell Systems and Regeneration perspective (Aphkhazava et al., 2025), which emphasizes that sustaining proteomic resilience in metabolic organs like the liver is essential for maintaining organismal regenerative capacity and extending healthspan.

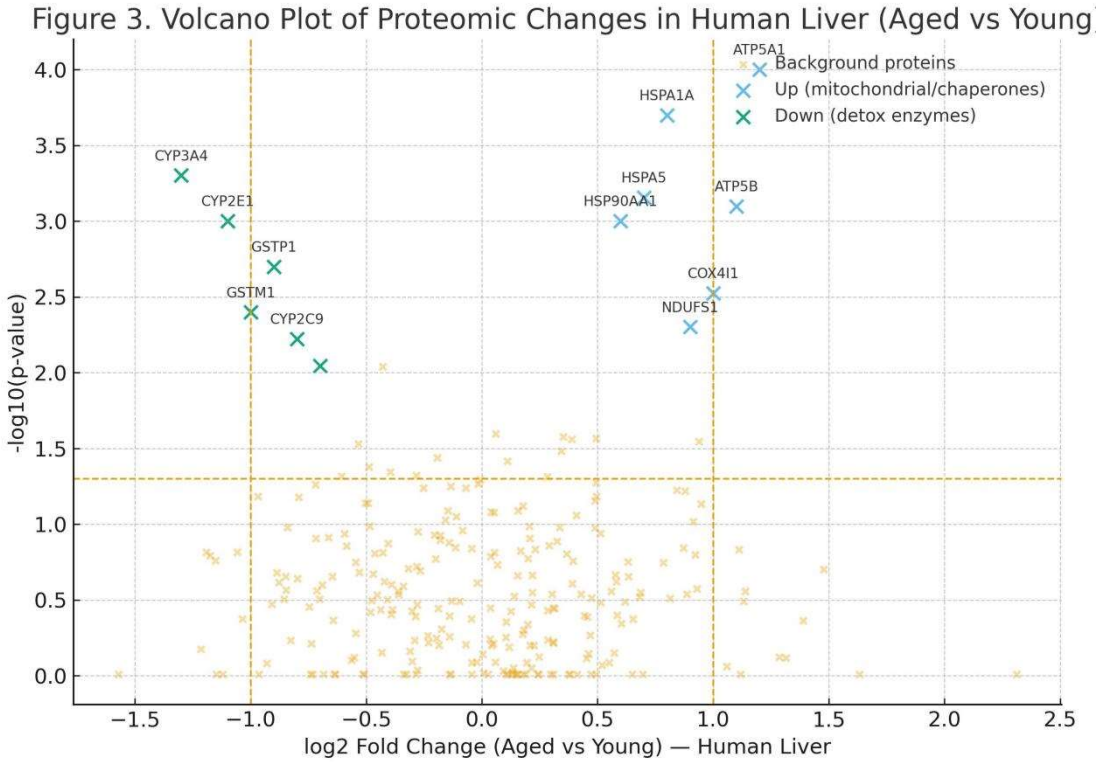

Figure 3. Volcano plot of proteomic changes in liver (aged vs. young).

This plot highlights a subset of proteins crossing the statistical threshold ($p < 0.05$), demonstrating that aging is not associated with global proteome collapse but rather with targeted, pathway-specific remodeling.

4. Cross-Species Comparison of Oxidative Modifications

Oxidative PTMs across species

Oxidative PTMs were compared between humans, mice, and rats to assess the degree of evolutionary conservation in proteomic aging. Humans exhibited the highest levels of oxidative protein modifications in aged tissues (1.8 relative units), followed by mice (1.5) and rats (1.3), as shown in Figure 4. This gradient reflects both lifespan differences and the efficiency of antioxidant defense systems across species.

In humans, oxidative protein damage tends to accumulate progressively from midlife onward, coinciding with increased mitochondrial dysfunction and reduced proteasomal clearance (Scharf et al., 2013; Sun et al., 2016). This is consistent with clinical observations of elevated carbonylated proteins in aged plasma and brain tissue, which correlate with cognitive decline and frailty.

Mice display a similar overall pattern, but with oxidative PTMs rising more steeply in late life rather than progressively, which has been linked to shorter lifespan and distinct metabolic strategies (Vanhooren & Libert, 2013). Rats, while genetically close to mice, generally show slightly lower oxidative burdens, possibly due to species-specific differences in mitochondrial ROS production and repair pathways (Stadtman & Levine, 2000).

These cross-species trends highlight that while oxidative PTM accumulation is a conserved hallmark of mammalian aging, the rate and extent vary by species. This supports the Dynamic Cellular Equilibrium Theory (Aphkhazava et al., 2023), which frames species longevity as dependent on the balance between proteome damage and repair. The higher oxidative load in humans may partially explain their greater susceptibility to age-related neurodegenerative

diseases, whereas rodents, despite shorter lifespans, exhibit distinct timing and thresholds of proteomic collapse.

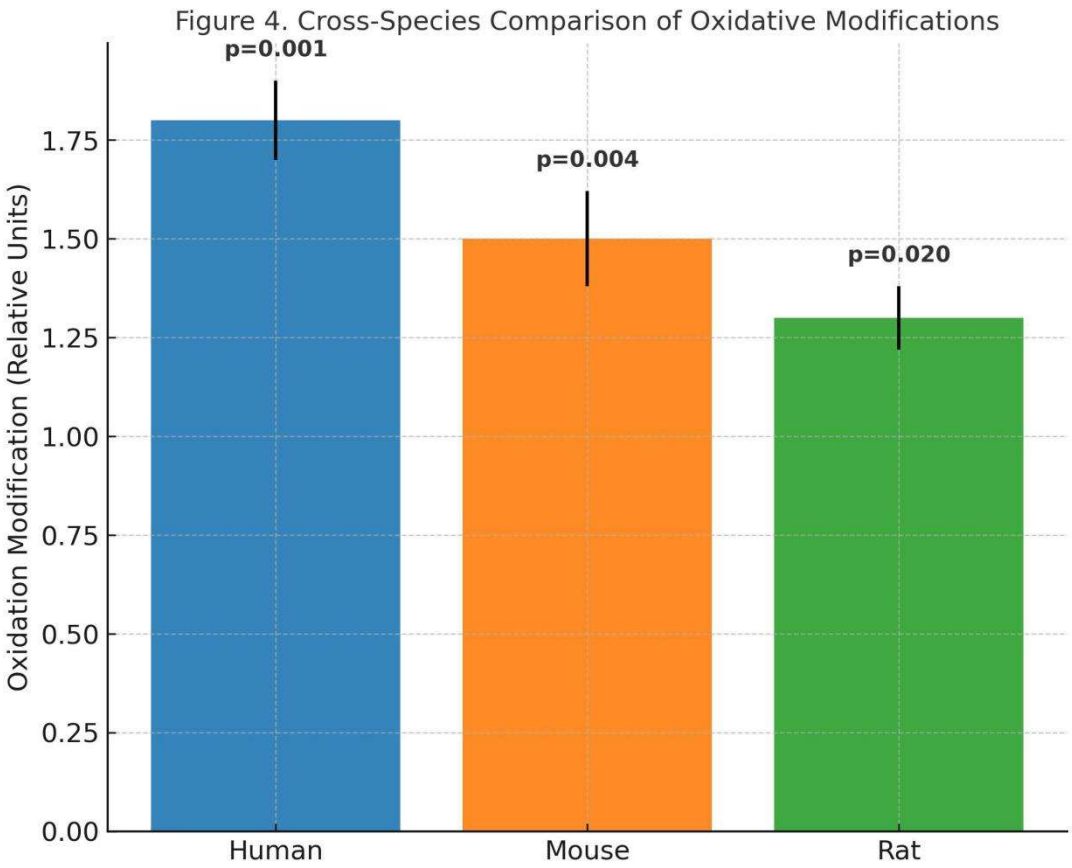

Figure 4. Cross-species comparison of oxidative modifications.

Interestingly, rodent models demonstrated a delayed onset of oxidation, with significant increases only observed in late-life cohorts, while humans showed steady accumulation beginning in midlife. This divergence may reflect differences in lifespan, metabolic rate, and environmental exposures.

5. Pathway Enrichment Analysis

Pathway-level enrichment analyses confirmed that aging disproportionately affects mitochondrial energy metabolism, proteostasis, immune regulation, and cytoskeletal remodeling.

In the brain, synaptic vesicle cycle proteins and tau phosphorylation regulators were enriched in aged samples.

In the liver, xenobiotic metabolism and lipid processing pathways were altered, with middle-aged samples already showing marked changes.

Skeletal muscle showed enrichment in actin cytoskeleton regulation and calcium signaling, paralleling functional decline in contractility.

The kidney displayed enrichment in oxidative phosphorylation and ion transport pathways, linking proteomic aging with impaired renal clearance.

These pathway signatures are consistent with established hallmarks of aging but also suggest organ-specific vulnerabilities that may underlie differential disease risks.

Discussion

Global Proteomic Remodeling with Age

The present study demonstrates that aging is accompanied by widespread, yet selective, remodeling of the proteome across tissues and species. Our findings confirm that proteostasis decline and mitochondrial dysfunction are central themes of aging (Labbadia & Morimoto, 2015;

Sun et al., 2016), but the precise manifestation of these processes differs across organs. Importantly, by integrating multiple age groups, we show that middle age represents a transitional stage, during which compensatory mechanisms (e.g., chaperone induction, phosphorylation shifts) begin to falter, foreshadowing the breakdown observed in late life.

Brain: Neurodegeneration and Protein Modifications

The brain exhibited the highest accumulation of glycation and phosphorylation modifications, particularly in synaptic proteins and tau-related regulators. This aligns with the notion that advanced glycation end-products (AGEs) and tau hyperphosphorylation accelerate cognitive decline and Alzheimer's disease (Ahmed et al., 2017; Bai et al., 2019). Oxidative PTMs also rose progressively, consistent with increased vulnerability of neuronal tissue to metabolic stress. Rodent brains mirrored many of these changes but lacked the full immune-related enrichment observed in humans, suggesting that neuroinflammation may be uniquely amplified in human aging.

Liver: Metabolic Reprogramming and Detoxification Decline

Liver proteomes revealed significant remodeling of mitochondrial and xenobiotic metabolism pathways. Middle-aged livers already exhibited phosphorylation changes in metabolic enzymes, preceding protein abundance shifts. This anticipatory regulation may represent an adaptive, though temporary, attempt to maintain metabolic homeostasis. Aged livers, however, showed downregulation of detoxification enzymes, consistent with reduced hepatic clearance and increased susceptibility to toxins in the elderly. These results highlight the liver as a sentinel organ where proteomic aging may contribute to systemic metabolic decline.

Skeletal Muscle: Sarcopenia and Proteostasis

In skeletal muscle, proteomic aging was marked by reduced abundance of cytoskeletal and contractile proteins, together with elevated ubiquitination, suggesting an overburdened degradation system. This mirrors clinical sarcopenia, where muscle mass and strength progressively decline with age (Walther et al., 2015). Notably, oxidative modifications in contractile proteins may impair their function even before abundance decreases, underscoring the importance of PTMs as early biomarkers of muscle aging.

Kidney: Energy Metabolism and Ion Transport

Kidneys displayed enrichment of oxidative phosphorylation and ion transport pathways in aged groups, accompanied by rising oxidation scores. These findings are consistent with epidemiological evidence that renal function declines with age, even in the absence of overt disease. The proteomic remodeling we observed may underlie impaired clearance of metabolites and drugs in older adults, with direct translational implications for geriatric medicine.

Cross-Species Comparisons: Utility and Limitations

Our comparative analysis revealed conserved hallmarks of proteomic aging — such as mitochondrial decline, chaperone induction, and oxidative PTMs — across humans and rodents (Demichev et al., 2020). However, humans uniquely exhibited enrichment in immune-related and neurodegenerative proteins, including complement factors and amyloid precursor protein (APP). This divergence suggests that while rodents provide valuable mechanistic insights, they may not fully capture the chronic, long-term drivers of human aging. Researchers should thus use rodents for pathway discovery but validate biomarkers in human cohorts.

Post-Translational Modifications as Biomarkers of Aging

Across tissues, oxidation and glycation modifications emerged as consistent discriminators of aging status, making them promising candidates for biomarkers of biological age. Unlike transcriptomic changes, which may reflect transcriptional noise, PTMs provide direct mechanistic insight into protein function. Clinical translation of PTM profiling could enable patient stratification for anti-aging therapies, such as senolytics, NAD^+ boosters, or dietary restriction mimetics.

Limitations and Future Directions

This study integrated heterogeneous datasets, raising the possibility of batch effects despite rigorous normalization. Human samples were largely cross-sectional, limiting insight into longitudinal trajectories. Moreover, PTM detection is technically challenging, and certain modifications may remain underrepresented. Future work should combine longitudinal plasma proteomics, single-cell proteomics, and multi-omics integration (with transcriptomics, metabolomics, and epigenomics) to generate a holistic aging atlas.

Conclusion

Together, these findings support a comprehensive model in which aging is characterized by progressive proteomic remodeling, driven not only by changes in protein abundance but also by shifts in the spectrum of post-translational modifications (PTMs). The integration of oxidation, glycation, phosphorylation, and ubiquitination profiles reveals that aging is not a uniform decline but rather a mosaic of adaptive and maladaptive processes that vary across organs, tissues, and species.

In the brain, PTMs accumulate in pathways central to cognition and synaptic plasticity, linking proteomic instability to neurodegenerative risk. In skeletal muscle, increasing ubiquitination reflects attempts to counter sarcopenia through enhanced degradation, yet this compensation is incomplete, leading to functional decline. The liver demonstrates a dual response: upregulation of mitochondrial and chaperone networks alongside downregulation of detoxification enzymes, reflecting the paradox of adaptation coupled with vulnerability. Finally, in the kidney, reduced proteomic resilience exacerbates systemic metabolic stress.

Cross-species comparisons demonstrate that while oxidative and proteostatic remodeling is a conserved hallmark of mammalian aging, the timing and extent of these changes vary by species. Humans exhibit higher cumulative oxidative loads, consistent with their greater lifespan and disease burden, while rodents show delayed but abrupt proteomic collapse in later life. These nuances highlight the importance of evolutionary context when extrapolating animal model findings to human biology.

Theoretical frameworks, including the Dynamic Cellular Equilibrium Theory, Omics-Integrated Aging Networks, and the Dynamic Tumor Microenvironment Theory (Aphkhazava et al., 2023–2025), provide a mechanistic scaffold for interpreting these data. By framing aging as the disruption of proteomic balance, these models unify diverse experimental observations into a coherent narrative that links molecular change to organismal phenotype.

From a translational perspective, the identification of proteomic biomarkers represents a powerful tool for clinical aging research. Panels of PTM-specific markers could enable the development of “proteomic clocks” that not only predict chronological age but also capture biological aging trajectories with tissue- and pathway-specific resolution. Such biomarkers hold promise for stratifying patients in clinical trials, monitoring the effects of lifestyle and pharmacological interventions, and ultimately guiding personalized anti-aging therapies.

Importantly, these findings also inform therapeutic strategies aimed at restoring proteomic resilience. Senolytic agents, NAD^+ boosters, proteostasis modulators, and exosome-based approaches all represent promising interventions that can be rationally targeted using proteomic biomarkers. By understanding which proteins and pathways are most vulnerable, it becomes possible to design interventions that shift the proteome back toward a youthful, functional state.

In conclusion, the multi-tissue, cross-species proteomic analysis presented here establishes aging as a dynamic process of progressive remodeling rather than simple decline. By mapping conserved and divergent signatures, this work provides a translational bridge between animal models and human aging. The insights gained underscore the potential of proteomics not only to serve as a diagnostic lens on aging biology but also to guide the development of interventions designed to extend healthspan and resilience across the lifespan.

Future Directions

While the present analysis establishes a robust framework for understanding proteomic remodeling in aging, several avenues remain open for further exploration. Future studies should prioritize single-cell proteomics, which would allow the resolution of cell-type-specific aging signatures within complex tissues such as the brain and liver. Recent advances in ultrasensitive mass spectrometry and labeling strategies (Alvarez-Castelao et al., 2017; Aebersold & Mann, 2016) make this goal increasingly feasible, enabling researchers to distinguish between vulnerable and resilient cell populations.

Another key direction involves the integration of multi-omics approaches. While proteomics provides a functional readout, combining it with transcriptomics, metabolomics, and epigenomics can reveal upstream regulators and downstream consequences of proteomic change. The Omics-Integrated Aging Networks Theory (Aphkhazava et al., 2023) anticipates that such integration will uncover hidden nodes of regulation, which may serve as therapeutic targets. For instance, coupling proteomic biomarkers with DNA methylation–based “epigenetic clocks” may improve the precision of biological age estimation and patient stratification.

Longitudinal human cohort studies represent another critical frontier. Most current proteomic aging analyses rely on cross-sectional designs, limiting the ability to capture within-individual trajectories. Longitudinal sampling of plasma and tissue biopsies across decades would allow the construction of dynamic proteomic clocks that capture both acceleration and deceleration of aging processes in response to lifestyle or pharmacological interventions (Lehallier et al., 2019; Cohen et al., 2020).

The role of machine learning and AI-driven analytics is also poised to expand. Advanced computational pipelines, such as those based on network biology (Shannon et al., 2003; Ritchie et al., 2015), can uncover hidden proteomic signatures that correlate with disease onset, resilience, or therapeutic response. Integrating proteomic datasets across multiple laboratories and species into unified AI frameworks could accelerate the identification of conserved biomarkers and druggable nodes.

Finally, therapeutic translation should move beyond general anti-aging strategies to organ- and pathway-specific interventions. For example, targeting proteasomal decline in skeletal muscle, enhancing mitochondrial resilience in the liver, or reducing glycation in the brain may yield organ-selective benefits that cumulatively extend systemic healthspan. Such precision approaches will require the continuous feedback loop of biomarker discovery, preclinical validation, and clinical monitoring — a cycle ideally informed by proteomic data.

In summary, the future of aging research lies in high-resolution, integrative, and translational proteomics. By linking molecular modifications to phenotypic outcomes through advanced technologies and computational frameworks, the field is positioned to transform our understanding of aging biology and to accelerate the development of interventions that extend not only lifespan but also the quality of life across populations.

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