

# **European Science Review**

**2026, No 7–8**

# European Science Review

Scientific journal

2026, No 7–8

ISSN 2310-5577

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**Homepage:**

ppublishing.org

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The journal has Index Copernicus Value (ICV) 92.08 for 2022.

SJIF 2024 = 6.735 (Scientific Journal Impact Factor Value for 2024).

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## Section 1. Architecture

DOI:10.29013/ESR-26-7.8-3-8



### FEATURES OF THE ORGANIZATION OF MULTIFUNCTIONAL SPACE IN MODERN APARTMENTS

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**Cite:** Sagaliyeva Zh. (2026). *Features of the organization of multifunctional space in modern apartments. European Science Review 2026, No 7–8.* <https://doi.org/10.29013/ESR-26-7.8-3-8>

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#### Abstract

The article discusses the characteristics of the organization of versatile space in modern apartments. It emphasizes that a contemporary living space should allow for the combination of various daily activities and be adaptable to the changing requirements of users. Theoretical foundations of functional zoning, techniques of space transformation, and the use of versatile furniture and integrated storage solutions are explored. The specifics of organizing kitchens, living rooms, bedrooms, workspaces, and other functional areas are examined. Special attention is given to current design trends, such as automation, quality of indoor environments, universal design, and energy efficiency. Key issues related to multifunctional spaces and criteria for assessing their efficacy are highlighted, including interoperability, privacy, acoustic comfort, mobility, rational space utilization, and adaptability.

**Keywords:** multifunctional space, modern apartment, residential interior, functional zoning, space transformation, multifunctional furniture, organization of the living environment, universal design, ergonomics, adaptability

#### Relevance of the study

A modern apartment is a space that accommodates various daily activities, such as rest, work, study, dining, socializing, and storing items. The rise of remote work and learning has increased the need for functional housing, with specific attention to the zoning and adaptability of spaces.

Under these circumstances, the efficient allocation of functional areas, use of transformable and multipurpose furniture, and

organization of space with ergonomics and comfort in mind are crucial. Scientific studies have shown that the characteristics of living environments directly impact the convenience and quality of daily life.

The relevance of this topic stems from the need to develop planning and design solutions that allow for the effective combination of several functions within a single apartment without compromising comfort. Therefore, studying the organization of multifunctional

spaces is of practical significance for modern architecture and interior design.

### **The purpose of the study**

The aim of this research is to identify the key features, methods, and current trends in the organization of multifunctional apartment spaces, as well as to establish criteria for assessing the efficiency of their use.

### **Materials and research methods**

The research materials included open scientific publications on the architecture and design of residential environments, as well as current regulatory documents that set out the requirements for residential spaces, their accessibility, ventilation, and engineering, such as SP 54.13330.2022, SP 59.13330.2020, and SP 60.13330.2020 (Set of Rules “Residential Multi-Apartment Buildings”).

In order to conduct the research, we employed methods such as analyzing scientific literature and regulatory documents, conducting comparative analyses, generalizing information about planning and interior solutions, and systematizing data.

### **The results of the study**

The basis of the organization of the residential interior is the relationship between the space and the functions performed in it. In studies on interior architecture, it is noted that changes in functions are reflected in the planning structure of the dwelling, while functional spaces and zones for specific human activities are formed in the room. Therefore, when designing an apartment, it is important to take into account the layout in conjunction with the real processes taking place in it and ensure that the location of the zones provides convenient connections between them (Efremova O. V., 2011, p. 191).

For multifunctional housing, it is important to have the ability to change the internal environment of the apartment without completely rebuilding it. In scientific literature, there are several ways to adapt an apartment space, including redevelopment, re-equipment, transformation, and functional variability. These methods allow one to change the purpose of different parts of the apartment based on the current needs of tenants (Korotkova S. G., 2011, p. 60).

In the design process, it is extremely important to take into account not only the functional distribution, but also the normative parameters of the space. According to SP 54.13330.2022, the dimensions of residential and auxiliary premises should be determined based on ergonomics and the placement of necessary equipment and furniture. The current version of this document also specifies the minimum floor space (SP 54.13330.2022).

One of the main techniques used in interior design is to change the boundaries between different areas. Sliding and folding partitions allow you to separate a bedroom, a work area, or other rooms, if necessary, and then combine the space again after opening. A study on limited living space, conducted in 2025, shows that open layouts and sliding and folding partitions are solutions that increase the flexibility of home use (Moumani, K.J., 2025).

Modern projects have also shown that a sliding partition can allow the same part of an apartment to change its level of privacy without the need for a permanent wall (Figure 1).

Another technique is the use of transformable furniture, where one element can perform several functions or change its configuration. This includes folding beds, folding tables, mobile seating, built-in wardrobes, and other structures.

A great example of this is the Barbican Dancer Studio in London, designed by Intervention Architecture. This apartment has a unique furniture design that incorporates a folding bed, storage space, seating, and a table into one piece. Some of these elements can be rearranged, freeing up the center of the room (Miller, E., 2020).

Another technique is to incorporate storage into the overall design of the interior. Rather than separate storage units, built-in cabinets, wall-to-wall systems, niches, drawers underneath seats, and other features that combine storage with other functions are used. For example, in the Barbican Dancer Studio project, the storage system was combined with a bed, shelves, and seating areas. Studies on multifunctional furniture also note the use of vertical space as a way to maximize the efficiency of small living spaces (Moumani, K.J., 2025).

**Figure 1.** *Examples of the use of sliding partitions for functional zoning of apartment space (Yeung, J., 2026)*



The arrangement of separate functional areas in modern apartments is based on the nature of daily activities and the need to separate public and private spaces. The pub-

lic areas usually include the kitchen, dining area, and living area, while the private areas include bedrooms, dressing rooms, and personal workspaces (Table 1).

**Table 1.** *Features of the organization of the main functional areas of a modern apartment*

| Functional area | Organization features                                                                                                                                         | Basic space requirements                                                                                                    |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| Kitchen         | Work surfaces and equipment are placed taking into account the sequence of basic household processes; convenient communication with the meal area is provided | Adequate work surface, safe placement of equipment, ventilation, lighting                                                   |
| Dining area     | It is located next to the kitchen or is part of the kitchen-living room; the space around the table should ensure convenient use of seating                   | Free access to the table, sufficient lighting, convenient connection to the kitchen                                         |
| Living room     | The layout is built around the main recreation area; the directions of movement between other rooms of the apartment are taken into account                   | Free movement, convenient furniture arrangement, natural and artificial lighting                                            |
| Bedroom         | It requires a greater degree of privacy compared to public spaces; it is desirable to limit intensive walking routes                                          | Quiet environment, possibility of dimming, ventilation, sufficient space to accommodate a bed and store personal belongings |
| Workplace       | It can be located in a separate room or be part of a living space; preferably located in a well-lit part of the space                                         | Adequate lighting, comfortable work surface and seating area, reduced exposure to household noise                           |
| Storage area    | It is organized taking into account the frequency of use of objects; it can be distributed between the hallway, bedroom and other rooms                       | Convenient access, efficient use of the area, no obstacles to passage                                                       |

| Functional area            | Organization features                                                                             | Basic space requirements                                                                               |
|----------------------------|---------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| Entrance hall and corridor | They provide the main routes of movement around the apartment and access to individual rooms      | Free passageways, no obstacles to movement, convenient placement of necessary equipment and furniture  |
| Bathroom and sanitary unit | The equipment is placed taking into account the convenience of use and engineering communications | Safety of operation, ventilation, moisture resistance of finishing materials, free access to equipment |

*A source: compiled on the basis of the provisions of SP 54.13330.2022, “Multi-apartment residential buildings,” SP 60.13330.2020, “Heating, ventilation and air conditioning,” as well as the results of research on the conditions of the organization of home workspace, published in the Journal of Environmental Psychology*

Modern design of living spaces is evolving in several interconnected directions, aiming to enhance convenience, improve the quality of the indoor environment, increase accessibility, and promote resource efficiency. These main areas of focus are presented in Table 2.

**Table 2.** *The main modern trends in the design of multifunctional living spaces*

| Direction                           | Main content                                                                                                           |
|-------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| Automation                          | Control of lighting, climate control equipment and engineering systems of the apartment                                |
| Quality of the internal environment | Ensuring adequate air exchange, comfortable temperature, lighting and acceptable noise levels                          |
| Using natural elements              | The use of natural lighting, plants and natural materials in the interior                                              |
| Universal design                    | Creating a space that is comfortable and accessible for people of different ages and with different physical abilities |
| Energy efficiency                   | Reducing the consumption of energy resources due to efficient engineering equipment and its operation management       |

*A source: compiled by the author based on SP 59.13330.2020 “Accessibility of buildings and structures for people with limited mobility,” SP 60.13330.2020 “Heating, ventilation and air conditioning,” and open scientific publications on the automation and organization of the modern living environment*

One of the current trends in the housing industry is the increasing use of automated management systems. These systems allow homeowners to control lighting, heating, ventilation, climate control equipment, and individual household appliances. This makes it easier to manage the engineering equipment in the apartment and allows for more accurate control of conditions in different rooms (Figure 2).

Considerable attention is given to the quality of the interior environment. The design takes into account air circulation, natural and artificial lighting, and temperature and acoustic conditions, which are directly

related to a person’s comfort when staying indoors.

Another aspect is the use of natural elements in interior design. Indoor plants, natural materials and textures are used in living spaces to enhance access to natural light. These solutions are part of a broader approach to creating a comfortable environment.

Also, the principle of universal design is developing, aiming to create spaces that are suitable for people of all ages and abilities. The design considers the width of aisles, ease of movement, accessibility of equipment, and the possibility of future space

modifications (Davydova E. M., Radchenko V. Yu., Radchenko O. S., 2016, p. 187).

The organization of air exchange is also important. Regulatory requirements ensure

a constant supply of fresh outdoor air to residential premises, and heat recovery systems can be used in modern apartments (Saifutdinova A. M., Kupriyanov V. N., 2009, p. 323).

**Figure 2.** *Examples of the use of home automation and natural elements in a modern living space (Arellano, M., 2023)*



After reviewing current design trends, it is important to consider how convenient such solutions are in everyday use. While multifunctionality alone does not guarantee a high-quality living space, an unsuccessful organization of multiple functions can lead

to conflicts in household processes, reduced privacy, and difficulty moving around (Bogdanov V. M., 2024, p. 529).

Table 3 presents the main challenges and criteria for assessing the effectiveness of multifunctional living spaces.

**Table 3.** *The main problems and criteria for the effectiveness of a multifunctional living space*

| Problem                                                   | The criterion of effectiveness | A sign of an effective organization                                                |
|-----------------------------------------------------------|--------------------------------|------------------------------------------------------------------------------------|
| Simultaneous performance of different types of activities | Functional compatibility       | Different processes do not significantly interfere with each other                 |
| and the spread of household noise                         | Acoustic comfort               | The noise of one zone does not interfere with the use of the other                 |
| Lack of privacy                                           | Privacy                        | Individual actions can be performed without constant visual and functional overlap |
| Inconvenient shape of the room                            | Suitability of the layout      | The space allows you to efficiently place furniture and equipment.                 |
| The intersection of traffic routes                        | Ease of movement               | The main passages do not pass through areas of permanent activity                  |
| Interior congestion                                       | Rational use of the area       | The necessary items are placed without hindering movement                          |
| The difficulty of changing the room's purpose             | Adaptability                   | The room can be used in different ways without significant remodeling              |
| Mismatch of the layout with household needs               | Functional compliance          | The space corresponds to real living scenarios                                     |

*A source: compiled by the author based on the general principles of functional organization and assessment of the quality of living space*

Thus, the effective organization of a multifunctional space does not mean filling the apartment with as many functions as possible, but rather a rational combination of them. The main criteria for this are functional compatibility, privacy, acoustic comfort, ease of movement, efficient use of space, and the ability to change the purpose of different parts of the room.

### Conclusions

The research conducted has shown that the effectiveness of a multifunctional space is not determined by the number of combined functions, but rather by the quality of

their interaction within the apartment. It is important to consider the rational distribution of functional areas, the ability to change the purpose of individual areas, maintaining privacy, acoustic comfort, ease of movement, and the ability to match the layout to real-life household scenarios. Modern design of multifunctional apartments must take into account both planning solutions and the requirements for interior quality, accessibility, and engineering equipment. This approach allows for the creation of a living space that adapts to the changing needs of users without the need for significant remodeling.

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submitted 15.08.2026;

accepted for publication 29.08.2026;

published 31.08.2026

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## Section 2. Economics and management

DOI:10.29013/ESR-26-7.8-9-18



### DIGITAL TAX ADMINISTRATION AND FISCAL CAPACITY PATHWAYS: EVIDENCE FROM ALBANIA AND SELECTED BALKAN COUNTRIES

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**Cite:** Mikel A. (2026). *Digital Tax Administration and Fiscal Capacity Pathways: Evidence From Albania and Selected Balkan Countries*. *European Science Review* 2026, No 7–8. <https://doi.org/10.29013/ESR-26-7.8-9-18>

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#### Abstract

This article examines the institutional pathway through which digital tax infrastructure may be converted into administrative capability and, in turn, contribute to fiscal capacity. It distinguishes transaction-data generation from the institutional capacity to govern, integrate, interpret and reuse information in repeatable tax-administration decisions.

A structured comparison of Albania and nine other Balkan jurisdictions draws on fiscal-capacity scholarship and organizational information-processing theory, together with legislation, European Commission reports, OECD and IMF assessments, national tax-administration material and peer-reviewed research. Conservative evidence rules distinguish operational use from announced or merely available systems; revenue effects are not estimated.

Digital reporting expands administrative visibility, but conversion paths differ. Greece provides a clear documented data-to-decision case within the evidence reviewed. Albania demonstrates direct reuse through value-added tax (VAT) return pre-filing and statutory automatic completion and submission after a missed filing deadline, while broader interoperability and data-use gaps persist. Slovenia and Croatia are reporting-led; Romania shows expanding integration; Serbia, Montenegro and Kosovo are integration-in-progress; North Macedonia and Bosnia and Herzegovina show more fragmented transitions.

The comparative evidence is consistent with a bounded capability-conversion perspective: digital adoption is not a proxy for fiscal capacity. For Albania, the priority is to extend governed, auditable and measurable data-to-decision capability beyond the documented VAT workflow.

**Keywords:** *digital tax administration; fiscal capacity; information utilization; e-invoicing; Albania*

## 1. Introduction

Fiscal capacity is the institutional ability to identify tax bases, implement policy, enforce liabilities and mobilize revenue predictably (Besley & Persson, 2009, 2011). Digitalization can expand administrative information without ensuring that it is converted into action.

E-invoicing, fiscalization, electronic filing and third-party reporting can expand transaction visibility and support pre-filing, consistency checks and risk segmentation. Evidence of compliance gains is conditional on implementation quality, connectivity, skills and complementary reform (Bellon et al., 2022; Hesami et al., 2024; Nose & Mengistu, 2023; Okunogbe & Pouliquen, 2022; Okunogbe & Santoro, 2023). Technology installation and institutional capability are therefore analytically distinct.

The article links fiscal-capacity research with organizational information-processing theory. Tax administrations must reconcile declarations, transaction records and third-party information; conversion requires governance, interoperability, analytical competence and organizational routines (Daft & Lengel, 1986; Tushman & Nadler, 1978). Data are recorded observations, information is data interpreted for an administrative purpose, and information utilization is their repeatable use in services, compliance management or policy decisions.

Albania is the focal case. Law No. 87/2019 established broad fiscalization and electronic invoicing, while the European Commission identifies further needs in using generated and third-party data and in interoperability (European Commission, 2025a, p. 73; Republic of Albania, 2019). Albania is compared with Slovenia, Croatia, Greece, Romania, Serbia, North Macedonia, Montenegro, Bosnia and Herzegovina, and Kosovo; the purposive comparison identifies documented configurations rather than ranks performance.

The analysis asks: (RQ1) through what pathway can digital infrastructure contribute to fiscal capacity; (RQ2) how do observable data-generation and information-utilization configurations differ across cases; and (RQ3) what capability gap remains most salient in Albania? The contribution is a bounded da-

ta-to-decision framework that separates infrastructure from utilization and applies explicit evidentiary limits.

## 2. Theoretical Framework

### 2.1 Fiscal Capacity as an Institutional Capability

Fiscal capacity is treated as a durable legal-administrative stock rather than a temporary revenue outcome (Besley & Persson, 2009, 2011). Digital systems may improve identification, verification, risk selection and policy feedback, but abundant data without governance or analytical routines can create visibility without conversion. Because the study does not estimate revenue gaps or causal fiscal effects, fiscal capacity remains a downstream construct.

### 2.2 Digital Tax Administration as an Information-Processing System

Digital tax administration changes decision processes, not merely filing channels. The OECD's Tax Administration 3.0 framework similarly treats digital identity, interaction, data, rules, governance and skills as interdependent capabilities (OECD, 2020). Information-processing theory explains why: more timely data reduce uncertainty, whereas equivocal classifications and taxpayer behavior require richer interpretation and organizational judgment (Daft & Lengel, 1986; Tushman & Nadler, 1978).

The framework therefore proceeds from digital transaction infrastructure to data visibility and quality, then to integration and interpretation through identifiers, reconciliations, rules and analytics, and finally to information utilization in pre-filing, taxpayer prompts, case selection or resource allocation. Legal authority, reliable identifiers, interoperability, analytical skills, cybersecurity, privacy, contestability and organizational routines condition each conversion stage. The final fiscal-capacity stage remains a theoretical pathway, not an observed outcome.

### 2.3 Information Utilization as a Conversion Capability

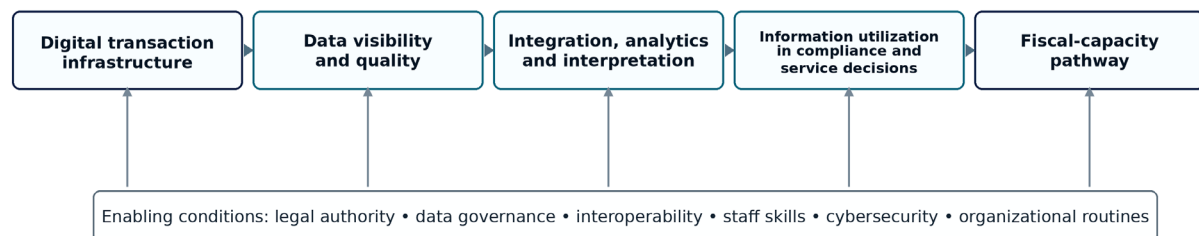
Information utilization is the repeatable and reviewable conversion of integrated data into services, compliance actions, management decisions or policy feedback. An e-invoice establishes collection, not use. Observable utilization requires an adminis-

trative consequence such as pre-filling, discrepancy prompts, risk-based case selection or changed resource allocation.

Empirical evidence reinforces the distinction: value-added tax (VAT) e-invoicing in Peru increased reported sales, purchases and liabilities, while electronic filing can re-

duce discretionary interaction, with effects depending on implementation (Bellon et al., 2022; Okunogbe & Pouliquen, 2022). Broader reviews likewise stress institutional reform and staff capability (Nose & Mengistu, 2023; Okunogbe & Santoro, 2023). Figure 1 summarizes the conversion sequence.

**Figure 1.** *Capability-conversion pathway from digital tax infrastructure to fiscal capacity*



*Note.* Author's framework. Arrows indicate theoretical expectations; they are not coefficients or causal estimates.

**Table 1.** *Construct definitions, observable evidence and analytical boundaries*

| Construct                          | Working definition                                                     | Observable evidence                                                   | Boundary                                       |
|------------------------------------|------------------------------------------------------------------------|-----------------------------------------------------------------------|------------------------------------------------|
| Digital transaction infrastructure | Capture/transmission of structured tax-relevant events.                | Fiscalization, e-invoicing, e-books, APIs, third-party reporting.     | Presence ≠ effective use or revenue impact.    |
| Data visibility and quality        | Timely, identifiable and standardized observable events.               | Coverage, identifiers, validation, completeness, correction.          | Public sources rarely permit accuracy audits.  |
| Integration and interpretation     | Linkage and conversion into administrative signals.                    | Interoperability, identifiers, reconciliation, risk rules, analytics. | Planned systems are transition, not operation. |
| Information utilization            | Repeatable use in service, compliance, management or policy decisions. | Pre-filling, checks, prompts, case selection, allocation, feedback.   | Collection alone is not utilization.           |
| Administrative capability          | Ability to implement tax law consistently and adapt operations.        | Skills, governance, processes, authority, security, review.           | No single maturity score.                      |
| Fiscal-capacity pathway            | Mechanisms through which capability may support durable mobilization.  | Coverage, compliance management, enforcement productivity, feedback.  | Not measured; no causal revenue claim.         |

*Note.* Definitions are used consistently in the framework, coding and interpretation

## 2.4 Research Propositions

Proposition 1 (visibility). Broad and timely digital transaction reporting increases the administrative visibility of taxable events when coverage and data quality are adequate.

Proposition 2 (conversion). Digital transaction infrastructure contributes to administrative capability only when data are integrat-

ed, interpreted and embedded in operational decisions.

Proposition 3 (complementarity). Legal authority, data governance, interoperability, staff skills, cybersecurity and organizational routines condition the conversion of digital data into usable information.

Proposition 4 (bounded fiscal effect). Any contribution to fiscal capacity is downstream and contingent and cannot be inferred from technology adoption or reporting volume alone.

### 3. Methodology

#### 3.1 Research Design and Case Selection

The study applies a structured, focused comparison of transaction capture, documented integration or reuse, and remaining capability constraints. Albania combines broad fiscalization with data-use and interoperability needs; four European Union (EU) member states and five other Western Balkan jurisdictions provide contrasting institutional configurations. Selection is purposive and the-

ory-oriented. The observation window begins in January 2019, while recent official assessments govern current country interpretation.

#### 3.2 Source Hierarchy and Inclusion Rules

Evidence comprises legislation and tax-administration material, European Commission assessments, OECD and IMF publications, and peer-reviewed research. Sources were included when they documented a traceable mandate, system, operational use or capability constraint. Coding favored operation over announcement, observable use over mere data availability, current evidence over historical descriptions, and triangulation where feasible; lack of public documentation was treated as an evidentiary limitation, not a negative score.

**Table 2.** Evidence rules used in the cross-country comparison

| Rule                        | Operational decision                                                          |
|-----------------------------|-------------------------------------------------------------------------------|
| Operation over announcement | Mandates/plans count only when implementation is documented.                  |
| Use over availability       | Data availability is not utilization without observable service/decision use. |
| Current over historical     | Recent official evidence governs current configuration.                       |
| Triangulation               | National evidence is compared with international sources when feasible.       |
| No inference from silence   | Missing public evidence is a limitation, not a negative score.                |
| No causal upgrading         | Pattern consistency is not proof of fiscal/revenue effects.                   |

*Note.* The rules are designed to prevent ordinal judgments that are not supported by traceable evidence

#### 3.3 Analytical Procedure

Documents were coded against Table 1 and summarized as evidence chains from transaction capture to administrative use. Data-to-decision denotes documented reuse; reporting-led denotes established collection without direct evidence of downstream use; integration-in-progress denotes operational services alongside integration or utilization gaps; fragmented transition denotes divided or planned integration without established system-wide reuse. Propositions are assessed by cross-case pattern matching, not statistical testing.

#### 3.4 Reliability, Validity and Limitations

Validity is supported by distinct constructs, explicit evidence rules and conserva-

tive coding. Coding was undertaken by one author, and the study contains no taxpayer microdata, administrative case records, interviews or comparable revenue-gap series. It therefore cannot rank jurisdictions, estimate fiscal effects or establish revenue causality.

### 4. Comparative Findings

#### 4.1 Cross-Case Configurations

The cases do not form a simple digital/non-digital or EU/non-EU hierarchy. The relevant distinction is how clearly transaction capture can be traced to an administrative service or decision.

Within the evidence reviewed, Greece provides a clear data-to-decision case: official sources describe myDATA electronic books,

real-time transmission and pre-filling of Form E3 from myDATA income and expense categories (European Commission, 2026 b; Independent Authority for Public Revenue, n.d.-a, n.d.-b). This documents administrative reuse, not an aggregate revenue effect.

Slovenia combines real-time fiscal verification with mandatory business-to-government (B2G) e-invoicing (European Commission, 2026d; Financial Administration of the Repub-

lic of Slovenia, 2019). Croatia combines structured B2G e-invoicing with national interoperability standards (European Commission, 2026 a). In both cases, the reviewed public evidence documents infrastructure more clearly than the downstream risk-analytics chain. Romania's RO e-Factura provides a technical basis for broader integration, but cross-functional use is not fully observable (European Commission, 2026 c; OECD, 2025).

**Table 3.** *EU-member reference cases: observed evidence and bounded interpretation*

| Case     | Transaction infrastructure                                | Integration/use                                                         | Configuration                         |
|----------|-----------------------------------------------------------|-------------------------------------------------------------------------|---------------------------------------|
| Slovenia | Real-time fiscal verification; mandatory B2G e-invoicing. | Digital channels established; full risk-analytics chain not documented. | Reporting-led.                        |
| Croatia  | Structured B2G e-invoicing; national CIUS.                | Interoperability standards visible; downstream analytics less so.       | Reporting-led.                        |
| Greece   | myDATA electronic books; real-time transmission.          | Pre-filling from myDATA income/expense categories.                      | Data-to-decision; no revenue claim.   |
| Romania  | RO e-Factura and related reporting.                       | Cross-checking potential; cross-functional use not fully observable.    | Reporting-led, expanding integration. |

*Note.* Principal sources are cited in the text. Configurations are descriptive and non-ordinal

#### 4.2 Western Balkan Cases

In the Western Balkans, electronic reporting often coexists with incomplete integration. Albania combines operational VAT-data reuse with broader gaps; Serbia has pre-filled VAT statements, while integrated-system implementation remained incomplete (European Commission, 2025 e, p. 14).

Montenegro operates e-fiscalization but still faces tax-IT and resource needs (European Commission, 2021; European Commission, 2025 c). North Macedonia's tax IT remains fragmented, with system replacement and compliance-risk management still reform priorities (European Commission, 2025 d, p. 74).

**Table 4.** *Western Balkan cases: observed evidence and principal capability bottleneck*

| Case            | Digital position                                                     | Documented gap/use                                                | Configuration            |
|-----------------|----------------------------------------------------------------------|-------------------------------------------------------------------|--------------------------|
| Albania         | Fiscalization/e-invoicing; VAT pre-filling and automatic submission. | Direct VAT reuse; broader data use/interoperability remain needs. | Integration-in-progress. |
| Serbia          | Electronic services; pre-filled VAT.                                 | Integrated system implementation incomplete.                      | Integration-in-progress. |
| North Macedonia | Digital services; integrated system planned.                         | Fragmented IT; risk management/replacement remain priorities.     | Fragmented transition.   |

| Case                   | Digital position                                | Documented gap/use                                                          | Configuration                             |
|------------------------|-------------------------------------------------|-----------------------------------------------------------------------------|-------------------------------------------|
| Montenegro             | E-fiscalization operational.                    | Further tax-IT development/capacity required.                               | Integration-in-progress.                  |
| Bosnia and Herzegovina | Digital initiatives across administrations.     | Fragmentation/interoperability constrain system-wide linkage.               | Fragmented transition.                    |
| Kosovo                 | Digital services and risk analytics documented. | Legacy IT, third-party data, quality and human capacity need strengthening. | Integration-in-progress; substantive use. |

*Note. The table records the dominant pattern visible in official sources; it is not a performance ranking*

Bosnia and Herzegovina continues to face interoperability constraints across separate tax administrations (European Commission, 2025b). Kosovo shows substantive operational use: risk-analysis modules and risk-based audits are documented, alongside legacy-IT, data-quality and human-capacity constraints (European Commission, 2024, p. 71). The International Monetary Fund (IMF) similarly highlights achievements in compliance-risk management while identifying further needs in third-party data, data quality and human resources (International Monetary Fund, 2025).

#### **4.3 Albania: From Fiscalization to Information Utilization**

Albania's fiscalization reform changed the informational basis of tax administration. Law No. 87/2019 established electronic invoicing and transaction reporting for cash and non-cash transactions, creating broad transaction visibility (Republic of Albania, 2019).

The remaining issue is the breadth and institutionalization of reuse. The European Commission distinguishes completed fiscalization digitalization from the need to improve use of generated information, third-party data and interoperability (European Commission, 2025a, p. 73). The gap is therefore incomplete linkage, interpretation and evaluated use across tax functions, not an absence of operational reuse.

A concrete data-to-decision mechanism is operational. From the April 2025 reporting period, e-Filing pre-fills VAT-return fields from fiscalization-derived sales and purchase books while allowing taxpayer review (General Directorate of Taxation, 2025). Law No. 79/2025 also requires automatic completion and submission within 24 hours after a missed

filing deadline; taxpayers may subsequently amend the return and remain liable for late-filing penalties (Republic of Albania, 2025, art. 11). Article 113 of Law No. 9920 sets those penalties at ALL 10,000 for corporate income tax taxpayers, ALL 5,000 for other non-individual taxpayers and ALL 3,000 for individuals (Republic of Albania, 2008, art. 113).

These mechanisms demonstrate reuse but not broad analytical maturity or fiscal effects. The public indicators reported by the General Directorate of Taxation (2024) do not permit a stable linkage between fiscalization signals and audit selection, voluntary correction, processing time, false positives or additional liabilities. Evaluation should therefore focus on the quality, timeliness and consistency of administrative decisions.

A practical Albanian architecture comprises five stages: govern data ownership, quality and access; link fiscalization, declarations and authorized third-party sources through stable identifiers; interpret data through documented rules or models; embed signals in prompts, pre-filing and case management; and evaluate outcomes, burden, bias, drift and appeals. This sequencing favors traceable high-value decisions over premature algorithmic complexity (OECD, 2022).

Priority use cases include invoice-chain reconciliation before VAT refunds, discrepancy prompts between fiscalized turnover and declarations, and sector-specific risk queues. Each requires a legal basis, accountable owner, data-quality test, decision rule, human-review protocol and performance metric. Relevant measures include match rates, signal-to-action time, correction and case-conversion rates, adjusted audit yield, appeals and false-positive rates.

**Table 5.** *A staged information-utilization agenda for Albania*

| Stage        | Priority action                                        | Evidence of operation                                 | Illustrative indicator               |
|--------------|--------------------------------------------------------|-------------------------------------------------------|--------------------------------------|
| 1. Govern    | Assign owners; define quality, access and correction.  | Approved catalogue and accountable owners.            | Completeness/time-liness.            |
| 2. Link      | Stable identifiers and authorized interfaces.          | Repeatable reconciliation with match/exception rates. | Match/duplicate rates.               |
| 3. Interpret | Transparent rules/models for selected risks.           | Versioned documentation and validation.               | Precision/recall; drift/bias.        |
| 4. Embed     | Connect signals to workflows, prompts and pre-filling. | Logs of action, review and resolution.                | Signal-to-action; conversion.        |
| 5. Evaluate  | Compare outcomes, burden and contestability.           | Regular benchmark/control evaluation where feasible.  | Net yield, false positives, appeals. |

*Note. Indicators are proposed for future administrative evaluation; the present study does not report their values*

#### 4.4 Proposition Assessment

Propositions 1–3 are consistent with the documentary pattern: reporting expands observable data; direct reuse differs across systems; and interoperability, governance,

IT capability and skills condition conversion. Proposition 4 remains an inferential boundary because the study lacks comparable outcomes, microdata and a causal identification strategy.

**Table 6.** *Summary of proposition assessment*

| Proposition         | Assessment            | Reason                                                          |
|---------------------|-----------------------|-----------------------------------------------------------------|
| P1: visibility      | Consistent            | Reporting expands observable data, subject to coverage/quality. |
| P2: conversion      | Consistent            | Reuse differs despite established infrastructure.               |
| P3: complementarity | Consistent            | Gaps concern integration, governance, IT and skills.            |
| P4: fiscal effect   | Not directly testable | No comparable outcomes or causal design.                        |

*Note. ‘Consistent’ denotes pattern correspondence, not statistical confirmation or causal proof*

#### 4.5 Discussion

The theoretical contribution is to position information utilization as a conversion capability between digital inputs and administrative outcomes. E-invoicing or fiscalization should not simultaneously serve as an indicator of reform adoption and evidence of improved administrative capacity. Transaction systems can reduce information gaps, but ambiguous classifications and taxpayer behavior still require cross-source interpretation, professional judgment and organi-

zational learning; fiscal outcomes remain downstream of these processes.

Comparative research should therefore distinguish infrastructure, workflow and evaluated outcomes rather than rely on unsupported maturity scores. Match rates, prompt responses, model precision, intervention time, appeals and taxpayer burden are more diagnostic of conversion. Technical interoperability matters analytically only when linked to the administrative decision it is intended to improve.

For Albania, policy should prioritize a limited portfolio of auditable information-use cases specifying the compliance problem, authorized data, matching logic, decision owner, taxpayer safeguards and evaluation design. Stable identifiers, shared definitions and accountable correction of conflicting records are prerequisites; technical connection alone does not make information usable. Analysts also need tax-domain expertise, operational teams need data literacy, and taxpayer-facing automation requires explanation, correction channels and proportionate human review.

The study is limited by uneven public reporting on internal analytics, language and reporting-cycle differences, and single-author coding. Future research should evaluate discrete information-use interventions with documented timing and comparison groups where feasible, examining reporting, payment, audit yield, persistence and taxpayer burden. Regional studies could compare reporting latency, identifier matching, automated validation, case-routing time and appeals without disclosing sensitive taxpayer data.

## 5. Conclusion

Digital tax administration can strengthen the informational foundations of the state, but digital infrastructure should not be treated as fiscal capacity itself. The analytical pathway developed here proceeds from transaction capture to data visibility, integration and interpretation, and then to repeatable administrative use. The documentary pattern is consistent with the first three propositions—visibility, conversion and

complementarity—whereas the downstream fiscal effect remains untested in the absence of comparable outcome data or causal identification.

Within the evidence reviewed, Greece provides a documented data-to-decision case; Slovenia and Croatia are reporting-led, while Romania combines broad reporting with expanding integration. Albania, Serbia, Montenegro and Kosovo are best characterized as integration-in-progress, although the type and depth of operational reuse differ, while North Macedonia and Bosnia and Herzegovina show more fragmented transitions. These configurations are descriptive rather than ordinal and should not be read as performance rankings.

Albania makes the capability-conversion problem particularly visible. Fiscalization has established broad transaction reporting, and the VAT workflow demonstrates direct reuse through pre-filing and statutory automatic completion and submission after a missed filing deadline. At the same time, wider use of generated and third-party data, interoperability and systematic evaluation remain incomplete. The immediate policy priority is therefore to expand governed, auditable and measurable data-to-decision capability across tax functions. The study does not estimate a revenue effect. Its contribution is to specify intermediate institutional mechanisms that can be observed and tested; future research using administrative microdata, implementation timing or credible quasi-experimental designs should assess whether improvements in these mechanisms translate into persistent fiscal gains.

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submitted 27.07.2026;

accepted for publication 10.08.2026;

published 31.08.2026

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## Section 3. Geodesy

DOI:10.29013/ESR-26-7.8-19-24



### IS SPACE EXPLORATION A NECESSITY OR AN INDULGENCE?

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**Cite:** Jason Wang. (2026). *Is Space Exploration a Necessity or an Indulgence?* European Science Review 2026, No 7–8. <https://doi.org/10.29013/ESR-26-7.8-19-24>

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#### Abstract

As humanity extends its reach beyond Earth, the growing cost of space exploration has prompted an important question: is space exploration a necessity or an indulgence? This paper defines a necessity as an investment whose long-term benefits justify its costs and opportunity costs, while an indulgence is an expenditure driven primarily by aspiration without sufficient societal returns. Through an analysis of technological advancement, human survival, geopolitical competition, and opportunity cost, this paper argues that the necessity of space exploration outweighs its indulgence. Space exploration has generated transformative technologies such as GPS, advanced imaging systems, and emerging space-based solar power; enabled more accurate climate monitoring and disaster prediction; and become increasingly important to national security and geopolitical competition. Although space programs involve substantial financial commitments and may divert resources from urgent social needs, these concerns largely reflect questions of resource allocation and governance rather than fundamental flaws in space exploration itself. Ultimately, space exploration represents not merely an aspiration to reach beyond Earth, but an increasingly essential investment in humanity's technological progress, security, and long-term survival.

**Keywords:** *Space exploration; technological advancement; human survival; geopolitical competition; opportunity cost; space technology; national security; economic impact*

#### 1. Introduction

On NASA's recent Artemis II mission, four astronauts made history by traveling farther from Earth than any humans had before. Nevertheless, despite the celebration surrounding this achievement, such missions raise a fundamental question: is space exploration a necessity or an indulgence?

The answer depends partly on how these terms are defined. In this paper, a **necessity** refers to an investment whose long-term benefits – including economic, technological, strategic, or humanitarian returns – justify its expenditure and opportunity cost. By contrast, an **indulgence** refers to an aspiration pursued without sufficient

consideration of cost, alternative uses of resources, or broader social benefits.

Space exploration is often criticized as an expensive pursuit when governments continue to face urgent challenges on Earth, including poverty, healthcare needs, education inequality, climate change, and natural disasters. However, judging space exploration solely by its immediate financial cost overlooks the broader benefits it generates. Technologies developed for space missions frequently become valuable civilian applications; satellites have become essential to monitoring and protecting Earth; and space capabilities increasingly influence national security and geopolitical power.

This paper therefore argues that **the necessity of space exploration outweighs its indulgence**, particularly because of its contributions to technological advancement, human survival, and geopolitical security. At the same time, the paper recognizes that space exploration can become indulgent when poorly designed programs consume excessive resources without sufficient public benefit.

## 2. Analytical Framework and Approach

To evaluate whether space exploration should be considered a necessity or an indulgence, this paper examines four interconnected dimensions: **technological advancement, human survival, geopolitical competition, and opportunity cost**.

First, technological advancement measures whether investment in space produces innovations and economic benefits beyond the space sector itself. Second, human survival considers the role of space-based technologies in climate monitoring, disaster warning, and planetary defense. Third, geopolitical competition examines the growing strategic importance of space capabilities to national security and international influence. Finally, opportunity cost addresses the strongest argument against space exploration: whether resources devoted to space would generate greater social benefits if invested elsewhere.

Rather than treating space exploration as inherently beneficial or harmful, this framework evaluates whether its long-term technological, humanitarian, economic, and strategic returns justify its costs.

## 3. Results and Discussion

### 3.1 Technological Advancement

Space exploration requires significant financial investment, but its technological and economic returns can extend far beyond the original missions. Compared with other areas of government spending, NASA's budget represents a relatively small proportion of total U.S. government expenditure. In FY2025, NASA requested approximately USD25.4 billion for space exploration, representing about 0.35% of U.S. government spending (NASA, 2024a; Office of Management and Budget, 2024). By comparison, U.S. military expenditure reached approximately USD919 billion (USAFacts, 2026). These figures suggest that space exploration, while expensive in absolute terms, does not necessarily constitute an unaffordable luxury.

More importantly, space exploration generates both direct technological achievements and **spin-off technologies** that benefit civilian society.

One of the most consequential examples is the **Global Positioning System (GPS)**. Beginning in 1978, the United States launched the first NAVSTAR satellite, eventually developing a fully operational satellite navigation system (NASA, 2023). GPS has since become essential to transportation, communication, agriculture, finance, emergency services, and countless consumer technologies. By 2017, GPS had generated an estimated USD1.4 trillion in economic value, while a global navigation-system outage could result in approximately USD1 billion in economic losses per day (O'Connor et al., 2019).

Space exploration has also stimulated the development of new energy technologies. One emerging example is **space-based solar power (SBSP)**. As global electricity demand is projected to increase substantially by 2050, researchers have explored whether solar energy collected in space could supplement terrestrial energy production (Space Solar, 2026). Solar panels operating in space can potentially achieve higher efficiency than conventional ground-based systems because they receive more consistent sunlight. SBSP could therefore become a long-term source of clean energy if technological and economic barriers are overcome.

The influence of space research is also visible in everyday consumer and medical technologies. Among more than 1,300 documented space-related spin-off technologies is the digital imaging technology used in smartphone cameras (Launius, 2011). Researchers at NASA's Jet Propulsion Laboratory developed complementary metal-oxide semiconductor (CMOS) image sensors while investigating improved spacecraft cameras. The technology was later commercialized and became widely used in consumer electronics, automobiles, and medical devices. The global CMOS image sensor market is projected to reach USD49.12 billion by 2030 (Grand View Research, 2024).

Similarly, digital image-processing techniques developed during the Apollo program helped researchers produce enhanced images of the Moon. These advances contributed to the development of modern medical imaging technologies, including CT and MRI systems.

Thus, the value of space exploration cannot be measured solely by the number of successful missions or discoveries made beyond Earth. Its broader value lies in its ability to stimulate technological innovation that eventually improves economic productivity and quality of life on Earth.

### **3.2 Human Survival and Planetary Protection**

Beyond technological advancement, space exploration has become increasingly important to humanity's ability to understand and protect its own planet.

Satellites provide critical data on climate change, atmospheric conditions, ice loss, deforestation, greenhouse-gas concentrations, and other environmental indicators. Weather satellites use sensors to detect electromagnetic radiation emitted or reflected by Earth, allowing scientists and meteorologists to monitor environmental changes at a scale that would otherwise be impossible (Mukhitdinova, 2023).

Space-based observation is equally important for disaster prediction and emergency response. Before modern weather satellites existed, populations had significantly less warning of approaching storms. During the 1900 Galveston Hurricane, for example, an estimated 6,000–12,000 people died and financial losses reached approximately

USD30 million (Galveston Historical Foundation, 2023). Today, satellite systems such as the Geostationary Operational Environmental Satellites (GOES) provide continuous monitoring across the Americas. During Hurricane Helene, satellite observations contributed to early identification and warnings that gave communities valuable time to prepare or evacuate (Doelling, 2024).

Space exploration also provides humanity with the ability to identify potential threats beyond Earth. Near-Earth asteroid detection programs continuously track objects whose trajectories could potentially intersect with Earth. For example, in May 2026, observations of asteroid 2026 JH2 enabled astronomers to calculate its trajectory and determine that it would pass Earth at a safe distance (Mandrovsky, 2026).

The importance of such monitoring becomes clearer when compared with the 2013 Chelyabinsk meteor event. Because the object was not detected in advance, there was little opportunity for warning. The resulting explosion damaged approximately 7,200 buildings and injured around 1,500 people (Howells, 2023).

Therefore, space exploration is not simply about discovering distant planets. It provides humanity with information and technologies that help monitor Earth, predict natural disasters, and potentially defend civilization against future planetary threats.

### **3.3 Geopolitical Competition and National Security**

The necessity of space exploration is also shaped by international politics. In an international system without a sovereign authority above states, countries must continually consider their own security and strategic interests. This condition contributes to what political scientists describe as the **security dilemma**, in which states increase their capabilities because they fear dependence on or vulnerability to other states (Jervis, 1978; Herz, 1950).

Space has increasingly become part of this competition. Modern military operations depend heavily on satellite communications, navigation, intelligence, and surveillance. The Russo-Ukrainian War demonstrated this dependence particularly clearly. Satellite infrastructure was targeted at the beginning

of the conflict, while Starlink terminals later helped maintain communications for hospitals, schools, critical infrastructure, and military operations in Ukraine (Bingen, 2025).

This example illustrates an important transformation: space capabilities are no longer isolated from events on Earth. Communications, navigation, intelligence, and military coordination increasingly depend on space-based infrastructure.

Space exploration also functions as an instrument of national power. China, for example, has identified space capability as a major component of its long-term national strategy and has pursued the development of an independent space infrastructure (Xinhua News Agency, 2017). Its BeiDou Navigation Satellite System provides an alternative to the U.S.-operated GPS system, reducing dependence on foreign infrastructure while strengthening China's technological and geopolitical autonomy.

The economic dimension of this competition is also significant. NASA's FY2023 economic impact report estimated that NASA supported more than 304,000 jobs and generated over USD76 billion in economic output (NASA, 2024b). Globally, the space economy expanded from approximately USD546 billion to USD570 billion between 2022 and 2023, accompanied by more than 26,000 additional jobs (Gorman, 2024).

Therefore, investment in space exploration is not simply an expenditure on scientific curiosity. For modern states, it increasingly represents an investment in technological independence, economic growth, national security, and geopolitical influence.

### ***3.4 Opportunity Cost: When Does Space Exploration Become an Indulgence?***

The strongest argument against space exploration concerns **opportunity cost**. Government resources are limited, and money spent on space programs could instead be used for healthcare, education, poverty reduction, or other immediate social needs.

Pakistan provides an illustrative example. During 2017–18, Pakistan had an average annual income of approximately USD1,641, with around one-third of its population living in extreme poverty. Nevertheless, its government allocated approximately USD43

million to its space program (Richter, 2020). Critics argue that such spending represents a poor allocation of scarce resources when basic human needs remain unmet.

Critics also raise concerns about the long timelines of space programs, which can make accountability difficult, and about government support for private space companies when the benefits may disproportionately accrue to corporations or wealthy individuals.

However, these concerns do not necessarily demonstrate that space exploration itself is an indulgence. Instead, they highlight the importance of **effective governance, prioritization, and resource allocation**.

A poorly designed or underfunded space program may indeed represent inefficient spending. Yet this does not mean that investment in space technology inherently produces low social returns. Even projects that fail to achieve their original objectives can generate scientific knowledge, engineering expertise, and technologies that contribute to future missions and civilian applications.

The key question, therefore, should not be whether governments should explore space at all, but **how much they should invest, which projects deserve funding, and whether the expected long-term benefits justify their opportunity costs**.

## **4. Conclusion**

Space exploration occupies a complicated position between necessity and indulgence. It requires substantial resources, and governments must remain accountable for how those resources are allocated. When a mission consumes excessive public funding without meaningful scientific, economic, humanitarian, or strategic value, it can reasonably be considered an indulgence.

However, the broader evidence demonstrates that space exploration increasingly functions as a necessity. It has generated transformative technologies such as GPS and advanced imaging systems; strengthened climate monitoring and disaster prediction; created economic activity and employment; and become essential to national security and geopolitical competition. Most importantly, it provides humanity with technologies and knowledge that may prove critical to addressing long-term threats to civilization.

Ultimately, space exploration is not simply about humans looking beyond Earth out of curiosity. Humanity increasingly depends on space-based infrastructure for communication, navigation, environmental monitoring, security, and technological progress. The challenge is therefore not to choose between space exploration and human welfare, but

to ensure that space exploration is conducted responsibly, strategically, and with the broader interests of humanity in mind.

Space exploration may have begun as an aspiration, but as civilization becomes increasingly dependent on space, it is becoming an essential component of humanity's progress, security, and long-term survival.

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submitted 21.07.2026;

accepted for publication 04.08.2026;

published 31.08.2026

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## Section 4. Philology and linguistics

DOI:10.29013/ESR-26-7.8-25-28



### THE DYNAMICS OF LEXICAL MEANING IN ENGLISH: COGNITIVE AND SEMANTIC MECHANISMS OF MEANING CHANGE

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**Cite:** Mikayilova A. (2026). *The Dynamics of Lexical Meaning in English: Cognitive and Semantic Mechanisms of Meaning Change*. European Science Review 2026, No 7–8. <https://doi.org/10.29013/ESR-26-7.8-25-28>

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#### Abstract

This article examines the word as a lexical unit, with particular emphasis placed on lexical meaning, semantic changes, and the processes underlying the formation of polysemy in the English language, including the role of metaphor and metonymy in this process. Based on a semasiological and systemic approach, the study analyzes the functions of words as both nominative and cognitive units, the ways in which their meanings develop under the influence of extralinguistic and intralinguistic factors, as well as the role of phonological convergence in the emergence of homonymy. The research further demonstrates that morphological, syntactic, and contextual mechanisms operate in interaction to eliminate formal ambiguity and maintain effective communication. The findings confirm that the lexicon represents a dynamic and self-regulating system in which semantic differentiation and formal economy coexist in parallel.  
*Keywords:* lexical meaning; semantic change; polysemy; homonymy; metaphorical and metonymic extension

#### Introduction

Language is not a static phenomenon; rather, it is a constantly evolving system of signs shaped by human cognition, culture, and social interaction. Each lexical unit carries its own unique developmental history, reflecting semantic changes, acquired meanings, and other linguistic phenomena. The English language demonstrates this characteristic particularly clearly due to its global spread, prolonged contact with various languages, and extensive

history of borrowing. These processes have enriched its vocabulary, providing it with both flexibility and diversity, while also introducing a certain degree of semantic ambiguity. Therefore, studying the lexicon of English involves not only examining its vocabulary, but also exploring layers of meaning, semantic development, and diachronic changes.

The word, as the fundamental unit of the lexicon, establishes a connection between language, cognition, and reality. Through

its nominative function, it represents objects, properties, processes, and relations of the extralinguistic world, while its function of generalization enables the classification of objects with similar characteristics under a single conceptual category. From this perspective, the lexical meaning of a word is not merely a reflection of reality; it also embodies the ways in which human consciousness perceives, interprets, and categorizes the surrounding world.

Lexical meaning is formed as a result of human cognitive activity and is based on mental processes such as comparison, generalization, classification, and abstraction. It represents human experience in a conceptualized form; however, during language use, it may adapt to new contexts and acquire additional semantic nuances. Therefore, words are not merely formal linguistic units but dynamic means of communication whose meanings are continuously shaped and renewed through interaction.

Lexical meaning is not limited to denotative content; it also includes connotative components that convey the speaker's attitude, emotions, and evaluation. For example, although *aunt* and *auntie* refer to the same individual, the latter carries an additional emotional connotation. Similarly, while the words *house* and *home* both denote a place of residence, *home* conveys additional emotional associations such as family, comfort, and a sense of belonging. This demonstrates that lexical meaning reflects not only objective reality but also the pragmatic and subjective dimensions of speech.

Semasiology studies the interrelations between the word, the concept, and the referent, as well as the semantic structure of polysemous words and the mechanisms underlying the emergence and development of meanings. Semantic changes often result from transformations in a society's cultural and historical development, which are reflected in the evolution of its conceptual system and language.

For instance, the word *girl* in Old English originally had the general meaning of "child," but over time, through semantic narrowing, it came to denote specifically a female child. Similarly, the word *cloud*, which initially referred exclusively to a natural phenomenon,

underwent metaphorical extension with the advancement of information technology and began to refer to systems for storing and accessing data on remote servers. These examples demonstrate that lexical meaning is continuously renewed alongside changes in human cognition and social development.

The present study focuses on the mechanisms of semantic change, particularly the role of metaphor and metonymy in the development of polysemy and homonymy in English. It aims to examine how these processes contribute to lexical expansion, semantic differentiation, and the dynamic nature of the English vocabulary.

### Method

The research employs a theoretical and descriptive approach based on the analysis of linguistic literature and examples from the English lexical system. The study applies principles of semasiology, cognitive linguistics, and historical linguistics to investigate the processes responsible for semantic development.

The analysis is based on the examination of lexical units that demonstrate semantic variation, including cases of polysemy, homonymy, metaphorical extension, and metonymic transfer. Examples such as *get*, *bank*, *foot*, *bridge*, *grasp*, *hand*, and *board* are analyzed in order to identify patterns of semantic expansion and differentiation.

The research also applies a diachronic perspective to trace how meanings develop over time and how initially connected meanings may become independent semantic units. Particular attention is given to cognitive mechanisms involved in meaning formation, including conceptual association, similarity, and contiguity.

Through comparative semantic analysis, the study investigates the relationship between metaphor, metonymy, polysemy, and homonymy, demonstrating how these phenomena interact within the English lexical system.

### Results

The analysis demonstrates that lexical meaning is a dynamic structure influenced by cognitive processes, cultural development, and historical change. Words function not only as linguistic signs but also as representations of human conceptualization and experience.

The study confirms that lexical ambiguity is an inherent characteristic of natural language and appears mainly in two forms: polysemy and homonymy. Polysemy develops when one lexical unit acquires several interconnected meanings. For example, the verb *get* demonstrates multiple related meanings, including “obtain,” “become,” and “understand.” These meanings form a semantic network based on historical and cognitive associations.

Homonymy differs from polysemy because it involves formally identical words with unrelated meanings. Examples such as *bank* (financial institution/river edge) and *pen* (writing instrument/animal enclosure) illustrate cases where identical forms represent separate semantic units.

The research also reveals that ambiguity does not prevent successful communication because language possesses compensatory mechanisms. Morphological and syntactic structures provide important interpretative signals. For example, in *I bought a book* and *Please book a room*, the grammatical function of *book* determines whether it functions as a noun or a verb.

Context and pragmatic information also play a significant role in meaning interpretation. Although multiple meanings may initially become activated during comprehension, contextual information allows speakers to select the appropriate interpretation. For example, the meaning of *bank* is determined by whether it appears in a financial context or a geographical context.

The analysis further demonstrates that metaphor is one of the main mechanisms responsible for semantic extension. Metaphorical transfer allows words to move from one conceptual domain to another based on similarity. Examples such as *foot* (body part → base of a mountain/page), *bridge* (physical structure → connection between ideas or people), and *grasp* (physical holding → understanding) illustrate how metaphor contributes to the development of polysemy. The verb *grasp* originally denoted the physical action of “holding” or “seizing,” but through metaphorical extension, it developed the meaning of “understanding” or “comprehending.” This semantic expansion is based on the conceptual relationship established between physical control and mental control,

and similar patterns of development can be observed across different languages. Comparable semantic extensions are evident in the use of the verb *see* in the sense of “understand” and the verb *rise* in the sense of “increase.” Each such metaphorical extension does not eliminate the original meaning; rather, it adds new and related semantic features to it (Lakoff, G., & Johnson, M., 2003).

Metonymy also plays a significant role in semantic development by creating associations based on conceptual proximity. Examples such as *the White House* (building → administration), *Hollywood* (place → film industry), and *the crown* (object → monarchy) demonstrate how meanings expand through associative relationships.

The findings indicate that metaphor and metonymy primarily contribute to the formation of polysemy; however, prolonged semantic development may weaken the relationship between original and derived meanings, eventually contributing to semantic separation and the emergence of homonymy.

### Discussion

The findings confirm that semantic change is a complex process resulting from the interaction of linguistic, cognitive, and social factors. The English lexicon develops through continuous adaptation, allowing words to acquire new meanings while preserving connections with earlier semantic structures.

Polysemy should not be considered a weakness or deficiency of language. Instead, it represents an essential feature of linguistic flexibility and efficiency. The ability of a single lexical unit to express multiple related meanings allows speakers to communicate complex ideas using a limited number of linguistic forms.

Metaphor and metonymy are particularly important because they demonstrate the cognitive foundations of semantic development. Metaphor expands meaning through perceived similarity between conceptual domains, while metonymy develops meaning through associations within the same conceptual framework. Both mechanisms reveal the relationship between human cognition and language organization.

Although metaphor and metonymy usually produce related meanings, historical

development may gradually reduce the transparency of these connections. When speakers no longer perceive the relationship between meanings, separate semantic units may emerge, contributing to homonymy. Therefore, homonymy can sometimes be viewed as the result of long-term semantic evolution rather than an entirely independent phenomenon. Metonymy develops meaning through associations within the same conceptual framework, including relations between objects, actions, institutions, and their representatives (Evans, V., 2019).

The study of polysemy and homonymy provides deeper insight into the organization

of the English lexical system. Words represent not only external reality but also human perception, cultural experience, and communicative intentions. Their changing meanings reflect the continuous interaction between language and society.

The analysis shows that, semantic development demonstrates the balance between stability and innovation in language. Through mechanisms such as metaphor and metonymy, the English lexicon constantly expands and adapts, reflecting the creativity and cognitive abilities of language users.

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submitted 24.07.2026;

accepted for publication 07.08.2026;

published 31.08.2026

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## Section 5. Transportation

DOI:10.29013/ESR-26-7.8-29-34



### INTEGRATED OPERATIONAL AND FINANCIAL CONTROL OF CAR-SHARING FLEETS: UTILIZATION, PRICING, AND VEHICLE HEALTH

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**Cite:** Loginov I.D. (2026). *Integrated Operational and Financial Control of Car-Sharing Fleets: Utilization, Pricing, and Vehicle Health*. *European Science Review* 2026, No 7–8. <https://doi.org/10.29013/ESR-26-7.8-29-34>

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#### Abstract

Car-sharing operators control three levers that jointly determine per-vehicle profitability: where vehicles are positioned, what price a trip carries, and whether a vehicle is mechanically fit to accept a booking. Operations research treats these three levers as separate problems, each with its own optimization literature and its own validated results. This review synthesizes findings on fleet allocation, dynamic pricing, and vehicle health monitoring in car-sharing operations, and examines two practitioner proposals that attempt to unify all three within a single computational and financial control architecture. Peer-reviewed studies calibrated against Zipcar and car 2 go data report utilization gains of 12 to 28 percentage points and pricing gains of 15 to 30 percent when relocation and pricing are optimized jointly; one peer-reviewed study extends this joint optimization to include vehicle charging state, the closest existing precedent for treating utilization, pricing, and a vehicle-condition variable within one control policy. No peer-reviewed model reviewed here extends that integration to mechanical health monitoring or to financial cost accounting. Two practitioner sources propose this extension: a diagnostic framework identifying fleet underutilization, static pricing, damage-related revenue leakage, and depreciation misaccounting as four linked deficiencies, and a computational architecture combining a Fleet Health Index, mixed-integer allocation, demand forecasting, and adaptive pricing into one operating system. Their reported benchmarks have not been independently tested against data the authors did not collect, a gap this review treats as a specific and correctable limitation. It is not a reason to dismiss the underlying architecture.

**Keywords:** *car-sharing, fleet utilization, dynamic pricing, vehicle health, predictive maintenance, financial control, integrated fleet management*

#### Introduction

A car-sharing vehicle earns revenue only when three conditions hold at once: it sits

where demand exists, its price matches what that demand will bear, and it is mechanically able to complete the trip. Each condition

has generated its own line of research. Fleet allocation research formulates vehicle positioning as a stochastic or robust optimization problem, with strategic decisions such as fleet size fixed before demand is realized and relocation decisions responding to the realized state (Nair & Miller-Hooks, 2011; Kek, Cheu, Meng, & Fung, 2009). Pricing research draws on revenue management theory developed for airline seat inventory and adapted to vehicle-sharing fleets, treating price as the lever that shifts demand toward available supply (Talluri & van Ryzin, 2004; Jorge, Molnar, & de Almeida Correia, 2015). Vehicle health research is newer and comes from a different tradition entirely, applying predictive maintenance and damage-detection methods built for industrial fleets to the specific wear patterns of shared vehicles (Chaudhuri & Ghosh, 2021; Hasan, Nguyen, Boo, Jahani, & Ong, 2025).

Golalikhani, Oliveira, Carravilla, Oliveira, and Antunes (2021) note in their review of carsharing decision-support research that allocation, pricing, and asset-condition tools have developed as parallel, non-communicating research streams; business-model research on shared mobility has treated revenue architecture separately again from either (Cohen & Kietzmann, 2014). A joint routing, charging, and pricing policy for an autonomous electric fleet comes closest to bridging two of these streams, demonstrated with a Manhattan and San Francisco case study showing that a real-time policy solved through reinforcement learning keeps customer queues far shorter than a static policy while sustaining profit (Turan, Pedarsani, & Alizadeh, 2020). Charging state functions in that model as a proxy for one dimension of vehicle condition, energy availability, but the model does not extend to mechanical wear, damage, or the depreciation accounting that determines whether a given vehicle is still profitable to operate at all. No model reviewed for this article treats utilization, pricing, and mechanical health as components of a single objective function.

Mamaev (2026a) gives the same gap a financial framing. Fleet utilization coefficients in U.S. and European operators cluster between 0.35 and 0.45 against

a theoretical optimum above 0.70 under demand-responsive pricing and repositioning, and this shortfall is attributed to four linked deficiencies: underutilization from the absence of real-time repositioning intelligence, revenue foregone through static pricing, revenue leakage from vehicle damage and user misconduct that conventional monitoring detects too late to recover, and cost accounting that misrepresents vehicle-level profitability by relying on static depreciation schedules instead of usage-derived data. Mamaev (2026c) proposes a computational architecture built to close all four gaps within one operating system, combining demand-weighted zone partitioning, a Fleet Health Index, mixed-integer vehicle allocation, and adaptive pricing.

### Methods

Coverage was built from Transportation Research Parts A, B, C, and E, Transportation Science, Manufacturing & Service Operations Management, Operations Research, the European Journal of Operational Research, Energies, and WIREs Data Mining and Knowledge Discovery, using search terms combining “carsharing,” “fleet allocation,” “dynamic pricing,” “vehicle relocation,” “predictive maintenance,” and “vehicle health monitoring.” Studies qualified if they formulated fleet positioning, pricing, or vehicle-condition decisions as an explicit optimization or predictive model with a reported quantitative result, whether validated against real operator data, a simulation calibrated to real trip data, or a laboratory dataset representative of fleet telematics. Studies confined to ride-hailing driver labor questions, or to vehicle maintenance in contexts unrelated to commercial or shared fleets, were excluded.

Selected sources were grouped into three domains matching the three operational levers: fleet allocation and utilization, pricing under demand uncertainty, and vehicle health and maintenance. Studies addressing more than one domain within a single model, principally Turan, Pedarsani, and Alizadeh (2020) and the two practitioner sources, are discussed under the domain that constitutes their primary contribution, with cross-references where relevant.

## Results

Illgen and Höck (2019). – P. reviewing this literature, identify a consistent pattern across studies: utilization gains from optimized relocation are largest precisely where fixed-schedule baselines perform worst, meaning the value of optimization is concentrated in the high-variance operating conditions that free-floating car-sharing produces routinely.

A virtual zone concept addressing the imbalance problem jointly constrains vehicle relocation range and customer walking distance, reporting reduced reliance on staff-based relocation compared with pricing or relocation applied separately (Huang, An, de Almeida Correia, Rich, & Ma, 2021). Hosseini, Milner, and Romero (2025) show that a computationally simple balanced myopic relocation policy approaches the performance of an intractable optimal benchmark as network size grows, a result with direct implications for real-time deployment at city scale. The utilization gap between fixed-schedule baselines and optimized relocation identified across this literature is consistent in direction with the diagnosis in Mamaev (2026a) discussed in the Introduction; the peer-reviewed studies isolate the effect through controlled comparison, while the practitioner figure is a broader synthesis estimate.

The conceptual foundation for treating price as an active demand-management lever, distinguishing quantity-based control from price-based control in capacity-constrained service settings, comes from revenue management theory developed for airline seat inventory (Talluri & van Ryzin, 2004). Jorge, Molnar, and de Almeida Correia (2015) apply zone- and time-of-day differentiated pricing to a station-based network and find that price variation reduces the imbalance that would otherwise require relocation. Extending pricing and fleet-sizing decisions jointly to electric vehicle fleets, Xu, Meng, and Liu (2018) show that price-responsive demand models produce materially different optimal fleet sizes than models treating demand as fixed.

Lu, Chen, and Shen (2018) apply a two-stage stochastic integer program to a Zipcar dataset from the Boston-Cambridge market and separate two effects that pricing research had previously conflated: exogenously given

one-way demand increases profitability under favorable price differentials, while endogenously generated one-way demand, arising from the pricing decision itself, can decrease profitability if the price differential ignores that behavioral response. The value of repositioning has been quantified against car2go operational data using a distributionally robust optimization model, with a simple threshold policy performing close to the exact dynamic programming solution while remaining tractable at scale (He, Hu, & Zhang, 2020).

Turan, Pedarsani, and Alizadeh (2020) formulate the most complete peer-reviewed integration identified in this review, jointly optimizing routing, battery charging, and pricing for a profit-maximizing autonomous electric fleet through a deep reinforcement learning policy, and validate the approach in Manhattan and San Francisco case studies. Charging state operates in that model as the only vehicle-condition variable included in the objective function.

Mamaev (2026a) treats static pricing as one of four deficiencies driving underperformance, and the architecture proposed in Mamaev (2026c) implements adaptive zone-level pricing as one module within a larger system that also allocates vehicles and forecasts demand through a hybrid statistical-machine-learning model.

Vehicle condition entered the fleet-management literature later than positioning or pricing, mostly through work originally built for industrial and logistics fleets. Chaudhuri and Ghosh (2021) demonstrate a hierarchical fuzzy support-vector-machine architecture that classifies component health from telematics streams at lower computational cost than comparable ensemble methods. Hasan, Nguyen, Boo, Jahani, and Ong (2025). – P. reviewing artificial-intelligence-based vehicle damage detection across insurance, resale, and fleet-management applications, find deep-learning image classification mature enough for deployment, with dataset gaps concentrated in minor and underbody damage, the categories most relevant to shared-fleet wear. AI-driven prognostics have been applied to predict electric vehicle battery degradation from telematics-derived charge and discharge data (Cavus, Dissanayake, & Bell, 2025). A related form of condition

enters fleet planning directly in work modeling battery state of charge as a continuous function instead of discrete bins, reporting improved fleet-sizing accuracy against models that treat charging time as fixed (Huang, An, & Correia, 2020). Charging infrastructure decisions carry financial consequences for a shared electric fleet independent of any pricing or relocation policy layered on top, since the number and placement of chargers constrains how much of the fleet can be simultaneously available regardless of how well demand is forecast (Chen, Kockelman, & Hanna, 2016).

None of these studies embeds vehicle health as a hard constraint inside an allocation model the way Nourinejad et al. (2015) or Huang, An, de Almeida Correia, Rich, and Ma (2021) embed relocation decisions. Mamaev (2026c) takes that step: a composite Fleet Health Index built from five weighted sub-indicators, mileage, age, maintenance history, sensor telematics, and availability, feeds into a rolling-horizon mixed-integer program governing which vehicles are eligible for assignment. Vehicles below a maintenance threshold are withheld from allocation; vehicles below a lower threshold are flagged for retirement review. Benchmarking reported alongside the architecture associates it with a reduction in unplanned downtime of approximately 51 percent, a demand fulfillment rate of 92 percent, a 25 percent reduction in per-trip repositioning cost, and an 18-month extension of average fleet life cycle, measured against unspecified prior-art baselines and produced by the same source that designed the system.

### Discussion

Utilization, pricing, and vehicle health each have a validated peer-reviewed literature, and each literature shows the same pattern: optimization built on realized demand and realized fleet condition outperforms static baselines by a wide margin. Turan, Pedarsani, and Alizadeh (2020) is the only peer-reviewed model reviewed here that combines two of the three levers, pricing and a vehicle-condition variable, within a single control policy, and it does so only for battery charge; mechanical wear and damage sit outside its scope. That is a narrow slice of what “vehicle health” means

for a car-sharing operator whose largest condition-related costs come from collision damage and component failure. Energy state is a small part of that picture.

Mamaev propose a considerably wider integration: allocation, pricing, mechanical health, and financial accounting inside one system. The diagnostic claim that static depreciation accounting misrepresents vehicle-level profitability has no counterpart anywhere in the peer-reviewed literature summarized in Table 1; none of the allocation, pricing, or maintenance studies reviewed here treat cost accounting as part of the same decision problem as fleet positioning or pricing, even though a vehicle’s true operating cost depends on the same usage and condition data those studies already collect. The architecture proposed to close that gap builds a Fleet Health Index that governs allocation eligibility, a structural move with a real precedent in how Nourinejad et al. (2015) and Huang, An, de Almeida Correia, Rich, and Ma (2021) already embed relocation constraints inside allocation models. Extending that same logic to a health constraint is a reasonable design choice. It is not, on the evidence available, a tested one. The reported reductions in downtime and repositioning cost come from the same source that designed the index, measured against unspecified baselines, without a sensitivity analysis on the five sub-indicator weights and without replication against an operator’s data collected independently of the author. Peer-reviewed relocation and pricing studies in this review were validated against Zipcar, car2go, Manhattan, and San Francisco datasets collected by researchers external to the model’s design; the practitioner benchmarks have not cleared that bar yet.

Turan, Pedarsani, and Alizadeh (2020) is suggestive on this point but limited to two levers and one vehicle-condition dimension. Almost all of the fleet-allocation and pricing studies reviewed here validate their models against a single operator’s data, Zipcar or car2go, and generalization to operators with different fleet composition, vehicle age distribution, or regional damage and theft rates has not been systematically tested. The vehicle-health literature reviewed draws mainly on industrial IoT and electric-vehicle

contexts; direct evidence on mixed internal-combustion and electric fleets under the specific duty cycle of urban car-sharing remains limited, a gap that also affects how far the Fleet Health Index concept in Mamaev (2026 c) can be assumed to generalize beyond the conditions under which it was designed. The narrative protocol used in this review, without a systematic screening record, is a further limitation already noted in the Methods section.

### Conclusion

Fleet allocation, pricing, and vehicle health in car-sharing operations have each

produced a validated body of peer-reviewed research, and the one peer-reviewed study that combines two of these levers, Turan, Pedarsani, and Alizadeh (2020). – P. shows that joint optimization sustains profitability with substantially better service quality than single-lever control. What the peer-reviewed literature has not done is extend that integration to mechanical health, damage-related revenue leakage, or depreciation accounting. Mamaev (2026 a) identifies this as a financial control problem as much as an optimization problem, and Mamaev (2026 c) specifies a computational architecture built to address all four deficiencies inside one system.

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submitted 28.07.2026;

accepted for publication 11.08.2026;

published 31.08.2026

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## Section 6. Chemistry

DOI:10.29013/ESR-26-7.8-35-41



### EFFECT OF BULK MICELLIZATION ON THE REDUCTION OF SURFACE TENSION IN AQUEOUS SURFACTANT SOLUTIONS

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**Cite:** Derman S., Maryaskin Y. B., Maslak H. S., Netronina O. (2026). *Effect of Bulk Micellization on the Reduction of Surface Tension in Aqueous Surfactant Solutions*. *European Science Review* 2026, No 7–8. <https://doi.org/10.29013/ESR-26-7.8-35-41>

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#### Abstract

This study considers the possible effect of micellization in the bulk solution on the reduction of surface tension in aqueous surfactant solutions. Based on the Langmuir adsorption model and the Szyszkowski equation, the dependences of surface tension on concentration were analyzed for a number of surfactants.

It is shown that, for some of the systems considered, before the critical micelle concentration is reached, the dependence of the change in surface tension on  $\ln C$  is close to linear, while the calculated surface coverage at the CMC is 95,2–100%. For some ionic surfactants, deviation from linearity is observed even before the CMC is reached. It is assumed that such behavior may be associated with premicellar association of surfactant molecules and a decrease in the fraction of monomeric forms directly available for adsorption. At higher concentrations, the subsequent change in surface tension may be associated with structural reorganization of micellar aggregates and a change in the nature of their growth.

The results obtained show that, when considering the adsorption properties of surfactant solutions, it is necessary to take into account not only the state of the surface layer but also the association processes occurring in the bulk solution.

**Keywords:** *surfactants, adsorption, micellization, critical micelle concentration, Langmuir isotherm, Szyszkowski equation, surface tension*

#### 1. Introduction

As is well known, two spontaneous processes may occur in aqueous surfactant solutions: adsorption at the phase interface and

micellization in the bulk aqueous phase (Adamson A., 1979). In one of our previous studies, we suggested that these processes mutually influence the surface tension attained in

these solutions (Maruaskin Y., Derman S., 2019).

The effect of micellization on the adsorption characteristics of aqueous surfactant solutions should also be considered from a thermodynamic standpoint, based on the change in the chemical potential of monomeric surfactant forms in the bulk solution. Micelle formation does not imply direct displacement of surfactant molecules from the phase interface; however, upon reaching the critical micelle concentration, the activity of the monomeric forms changes much more slowly, which limits the further increase in surface adsorption and promotes stabilization of surface tension (Adamson A. W., Gast A. P., 1997; Rosen M. J., Kunjappu J. T., 2012; Tanford C., 1980).

In accordance with this assumption, the concept of the probability of occurrence of these processes was introduced (Maslak H. S., Maryaskin Y. B., Derman S., 2023). It was assumed that, at low concentrations, surfactant particles readily reach the interface and the adsorption process predominates. As the amount of surfactant in the bulk solution increases, the distance between individual particles decreases, the probability of their aggregation into micelles increases and, accordingly, the probability of adsorption decreases. Ultimately, adsorption reaches a constant value. According to (Fridrikhsberg D. A., 1974), this is observed at a surfactant concentration equal to the critical micelle concentration,  $C_k$ .

The concept of the probability of adsorption and aggregation used below is phenomenological and reflects the competition between the transport of surfactant molecules to the phase interface and their association in the bulk solution. In a thermodynamic approximation, such competition can be considered as a redistribution of monomeric surfactant forms between the surface layer and the bulk solution as their chemical potential changes (Rosen M. J., Kunjappu J. T., 2012; Myers D., 2006).

## 2. Theoretical Background and Calculation Method

Let us consider the above using the principles of Langmuir adsorption theory (Fridrikhsberg D. A., 1974). It should be taken into

account that this theory originally considered reversible adsorption at adsorption sites on the surface of solid particles. In the case of the solution-air interface, however, the liquid surface is homogeneous, and adsorption can occur on any free area of the surface.

It should be noted that applying the Langmuir isotherm to surfactant adsorption at the solution-air interface is an approximation. Unlike solid surfaces, the liquid-gas interface does not contain fixed adsorption sites, and lateral interactions between adsorbed molecules are possible in the surface layer. Nevertheless, in the range of moderate surfactant concentrations and in the absence of pronounced interactions, the Langmuir isotherm is widely used to estimate adsorption parameters (Adamson A. W., Gast A. P., 1997; Rosen M. J., Kunjappu J. T., 2012).

Let the total area of the air-solution interface be taken as unity, and let  $S$  denote the surface area occupied by the adsorbate. The surface area free of adsorbate will then be equal to  $1 - S$ .

According to the theory under consideration, adsorption is a reversible process, that is, at equilibrium the adsorption and desorption rates are equal.

In this case:

$$S = KC/(KC + 1) \quad (1)$$

where  $K$  is the adsorption equilibrium constant and  $C$  is the surfactant concentration in the solution.

The Szyszkowski equation, derived using the principles of Langmuir theory (Fridrikhsberg D. A., 1974), can be used to determine the adsorption characteristics of the process. According to this equation, up to the critical micelle concentration, a linear dependence should be observed in the coordinates  $\sigma_0 - \sigma = f(\ln C)$ , where  $\sigma_0$  is the surface tension of the solvent (water) and  $\sigma$  is the surface tension of the surfactant solution.

The Szyszkowski equation used here is related to the fundamental Gibbs adsorption equation and makes it possible to estimate the adsorption characteristics of the system from the change in surface tension with concentration. For real surfactants, especially ionic ones, such treatment should be regarded as approximate and applied within the concentration range in which the selected linear dependence is experimentally

observed (Adamson A. W., Gast A. P., 1997; Rosen M. J., Kunjappu J. T., 2012).

According to the Szyszkowski equation, the limiting adsorption ( $A_\infty$ ) can be calculated from the plot of  $\sigma_0 - \sigma$  versus  $\ln C$  using the tangent of the slope angle of the straight line ( $\alpha$ ):

$$\operatorname{tg} \alpha = A_\infty RT \quad (2)$$

where  $R$  is the gas constant and  $T$  is the temperature.

The adsorption equilibrium constant can be determined from the same plot using the intercept ( $a$ ) cut off by the straight line on the ordinate axis:

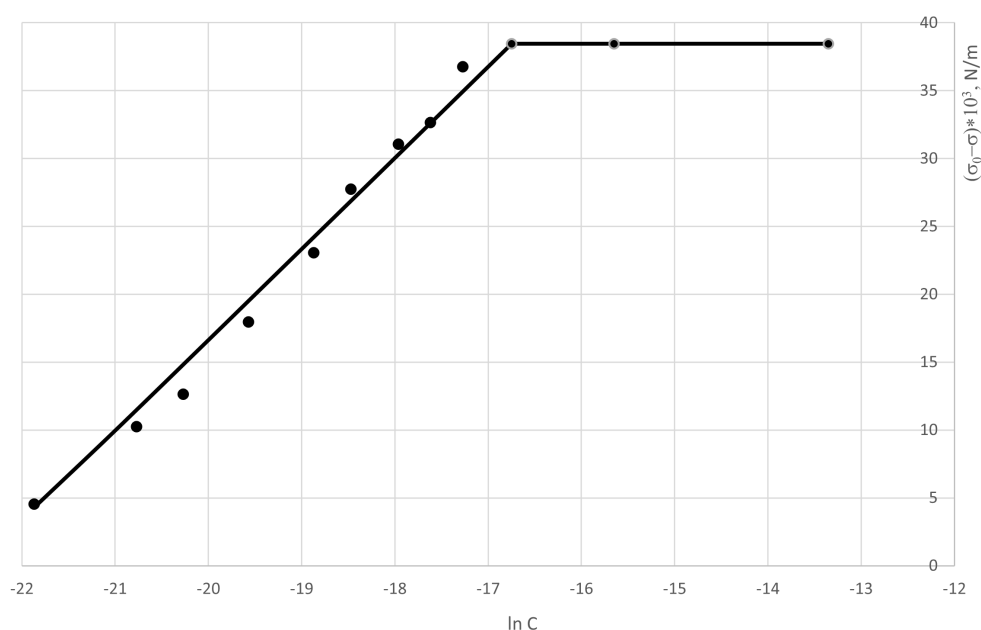
$$a = A_\infty RT \ln K \quad (3)$$

After determining  $A_\infty$  and  $K$ , the surface area occupied by the adsorbate can be calculated using equation (1).

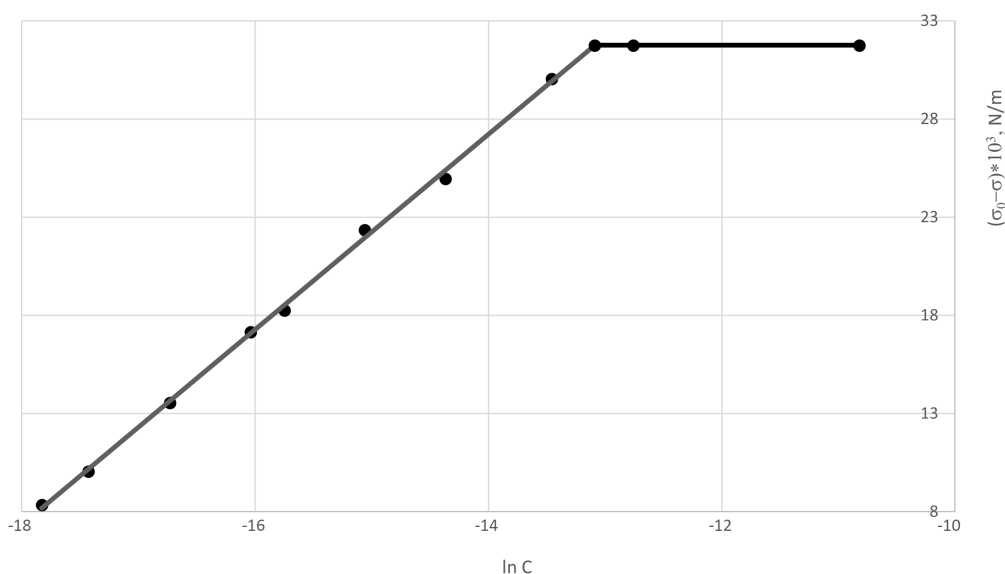
### 3. Results and Discussion

In the reasoning presented above, it is assumed that, up to  $C_k$ , either only the adsorption process occurs in the solution or micellization has little effect on this process. Figures 1 and 2 show that such an almost linear dependence of  $\sigma_0 - \sigma$  on  $\ln C$  is observed in a number of surfactant solutions.

**Figure 1.** Dependence of  $\sigma_0 - \sigma$  on  $\ln C$  for  $C_{14}H_{29}O(C_2H_4O)_8H$ ,  $T = 298\text{ K}$



**Figure 2.** Dependence of  $\sigma_0 - \sigma$  on  $\ln C$  for  $C_{12}H_{25}O(C_2H_4O)_{10}H$ ,  $T = 293\text{ K}$



The adsorption characteristics of these solutions, calculated using the equations given above, are presented in Table 1.

**Table 1.** Adsorption characteristics of surfactant solutions

| Surfactant                     | Ck,<br>mole fraction  | K                   | S, % | T, K |
|--------------------------------|-----------------------|---------------------|------|------|
| $C_{12}H_{25}O(C_2H_4O)_{10}H$ | $2,07 \times 10^{-6}$ | $3,2 \times 10^8$   | 99,8 | 293  |
| $C_{14}H_{29}O(C_2H_4O)_8H$    | $5,32 \times 10^{-8}$ | $17,19 \times 10^9$ | 100  | 298  |

As follows from the data obtained, in the solutions presented, when Ck is reached, the surface is almost completely covered with surfactant particles. With a further increase in concentration, micellization becomes intensive.

Before the CMC is reached, monomeric surfactant forms predominate in the solution, while the contribution of associated particles to the thermodynamic characteristics of the system generally remains relatively small. Therefore, within this concentration range, adsorption at the phase interface may remain the dominant process, which is manifested in the nearly linear dependence of surface tension on the logarithm of concentration (Rosen M. J., Kunjappu J. T., 2012; Myers D., 2006).

### 3.1. Deviation from Linearity and the Effect of Micellar Aggregation

However, the linear character of the dependence of  $\sigma_0 - \sigma$  on  $\ln C$  is not observed in all cases.

For example, as follows from Figures 3 and 4, in solutions of sodium dodecyl sulfate and sodium 4-hexadecyl sulfate, some deviation from linearity is observed even before Ck is reached. This may be associated with an increase in the probability of surfactant aggregation into micelles, which should reduce the rate of surfactant adsorption. Extrapolation of the linear section of the dependence of  $\sigma_0 - \sigma$  on  $\ln C$  shows that, if only an unhindered adsorption process occurred, the surface tension attained at Ck should be reached at a lower amount of surfactant (Figs. 3, 4). At the same time, in the case of sodium 4-hexadecyl sulfate, almost complete surface coverage by the adsorbate is retained (Table 2). Presumably, in this example micellization only slightly retards the transfer of surfactant to the surface.

Deviation from linearity at concentrations below the CMC may be associated not only with the formation of fully developed micelles, but also with premicellar association of surfactant molecules, the formation of dimers and oligomeric associates, as well as with enhanced lateral interactions in the surface layer. These effects reduce the fraction of monomeric surfactant forms directly available for adsorption and thereby may decrease the rate of further reduction in surface tension (Rosen M. J., Kunjappu J. T., 2012; Israelachvili J. N., 2011; Myers D., 2006).

In the case of sodium dodecyl sulfate, a somewhat lower degree of surface coverage by the adsorbate is reached at Ck (Table 2). It can be assumed that aggregation of particles into micelles constitutes a certain barrier that prevents attainment of adsorption equilibrium.

In this case, aggregation of surfactant molecules in the bulk solution can be regarded as a factor limiting attainment of adsorption equilibrium through a change in monomer activity. Such behavior may lead to a temporary slowdown in the increase in surface adsorption and may appear as inflections or plateaus in the concentration dependence of surface tension.

### 3.2. Structural Reorganization of Micelles and the Second Critical Concentration

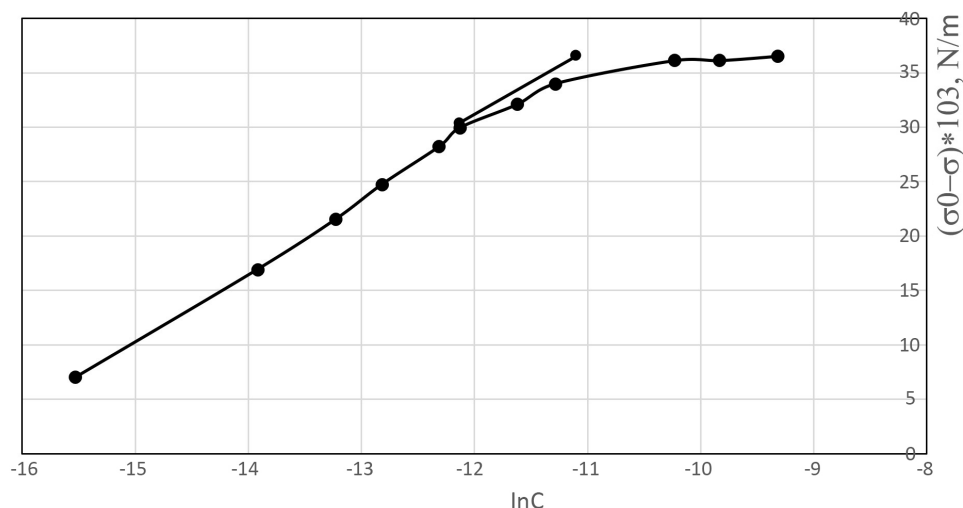
With a further increase in concentration, a repeated change in the character of the surface-tension dependence should not be unambiguously associated with the destruction of spherical micelles. In a number of systems, it may be accompanied by a change in the growth regime and structural organization of micellar aggregates. The transition from relatively weak to more intensive micelle growth is regarded in the literature as one of the manifestations of the second crit-

ical micelle concentration,  $C_{k,2}$  (Porte G., Poggi Y., Appell J., Maret G., 1984; Bergström L. M., 2016). Therefore, the observed further decrease in surface tension should be interpreted as a possible consequence of reorganization of the micellar system and the corresponding change in the equilibrium among monomeric surfactant forms, aggregates, and the surface layer.

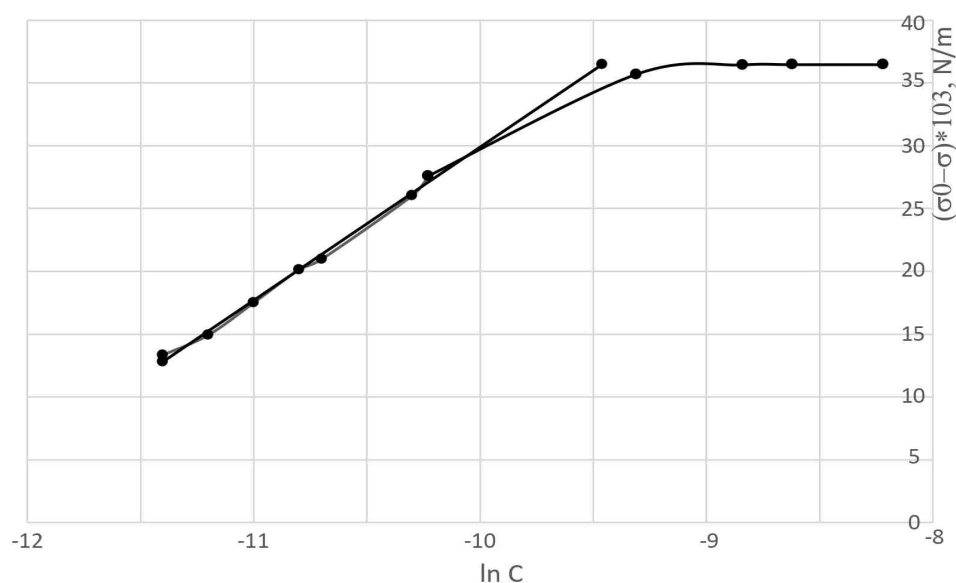
Depending on the nature of the surfactant and the solution composition, such structural reorganization may be accompanied by the formation of elongated or other nonspherical aggregates; however, establishing the specific morphology for the systems considered requires independent structural confirmation (Bergström L. M., 2016).

Early studies by K. Shinoda and co-authors demonstrated a substantial dependence of the critical micelle concentration, micelle aggregation characteristics, and self-organization processes on solution composition and the presence of electrolytes and organic additives (Shinoda K., 1954; Shinoda K., Nakagawa T., Tamamushi B., Isemura T., 1963; Shinoda K., 1954). These results are of historical and experimental interest in the context of the subsequent development of concepts concerning the structural evolution of micellar systems, whereas direct discussion of the second CMC is more appropriately associated with later studies (Porte G., Poggi Y., Appell J., Maret G., 1984; Bergström L. M., 2016).

**Figure 3.** Dependence of  $\sigma_0 - \sigma$  on  $\ln C$  for sodium 4-hexadecyl sulfate,  $T = 20^\circ \text{C}$



**Figure 4.** Dependence of  $\sigma_0 - \sigma$  on  $\ln C$  for sodium dodecyl sulfate,  $T = 293 \text{ K}$



**Table 2.** Adsorption characteristics of surfactants

| Surfactant                 | Ck,<br>mole fraction  | K                 | S, % | T, K |
|----------------------------|-----------------------|-------------------|------|------|
| sodium 4-hexadecyl sulfate | $8,99 \times 10^{-6}$ | $1,4 \times 10^7$ | 99,2 | 293  |
| sodium dodecyl sulfate     | $7,95 \times 10^{-5}$ | $2,5 \times 10^5$ | 95,2 | 293  |

#### 4. Practical Significance

It should be noted that the effect of micellization on the rate of formation of the adsorption layer may influence the technological properties of surfactant solutions. For example, in a cleaning process involving disruption of a contaminant layer, not only the reduction in surface tension but also the kinetics of transport of surfactant molecules and aggregates to the interface with the oil phase are important.

From a technological standpoint, not only the equilibrium value of surface tension but also the rate of formation of the surface layer is important. Therefore, surfactant association processes in the bulk solution, which change the concentration of available monomers and the kinetics of their transport to the surface, may potentially affect wetting, emulsification, and the cleaning action of the solutions. Specific kinetic measurements are required for quantitative confirmation of such an effect.

In subsequent studies, the authors intend to present the results of further investigation of the factors affecting the properties of surfactant solutions.

#### 5. Conclusion

The data considered show that, for some of the surfactants studied, the dependence of surface tension on  $\ln C$  before  $C_k$  is reached is close to linear, while the calculated degree of surface coverage at  $C_k$  approaches the limiting value. For ionic surfactants, deviation from linearity may occur even before the CMC and, along with the proposed probabilistic interpretation, may be associated with premicellar association and changes in the activity of monomeric surfactant forms. The Langmuir model and the Szyszkowski equation retain practical value as an approximate calculation framework in the region where the experimental dependence remains linear. A repeated change in surface tension at higher concentrations should be considered cautiously as a possible manifestation of structural reorganization and a change in the growth regime of micellar aggregates associated with the second CMC. The results obtained confirm the need for further joint analysis of the equilibrium and kinetic characteristics of adsorption and micellization.

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submitted 21.07.2026;

accepted for publication 04.08.2026;

published 31.08.2026

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