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WAYS TO ENHANCE THE ECOLOGICAL SUSTAINABILITY OF CITIES

Matanat Abdalova*

Department of Regional Development and Use of Natural Resources, Institute of Economics, Ministry of Science and Education, Baku, Azerbaijan

Abstract. This article examines the issue of urban environmental sustainability as one of the key directions of reforms being implemented worldwide in the context of balanced socio-economic development of regions. The study provides an analysis of contemporary academic research on urban policies for the development of the green economy, in which cities are considered not only as objects of regulation but also as active agents of the green transition. Special attention is given to international experience in the design and implementation of comprehensive measures aimed at achieving environmental sustainability in large cities. In addition, the article analyzes greenhouse gas emissions and the availability of green spaces in the cities of Azerbaijan, as well as the measures being implemented at the national and municipal levels to promote the greening of the urban economy.

Keywords: *Green economy, environmental sustainability, energy efficiency, green transport.*

Corresponding Author: *Matanat Abdalova, Department of Regional Development and Use of Natural Resources, Institute of Economics, Ministry of Science and Education, Baku, Azerbaijan, Tel.: +994706185449, e-mail: metanet.abdalova@mail.ru*

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1. Introduction

One of the main directions of reforms aimed at supporting the balanced socio-economic development of regions is ecological sustainability. In the modern era, one of the most pressing global problems is climate change and the significant impact cities have on it. Cities are major sources of increasing energy consumption and greenhouse gas emissions. According to the 2022 report of the Intergovernmental Panel on Climate Change (IPCC) (2022), cities account for 67-72% of emissions of carbon dioxide (CO_2) and methane (CH_4), which are considered the main greenhouse gases. This makes urban policy a critically important tool for climate and environmental regulation. It is necessary to implement effective measures in cities to mitigate climate change and monitor progress.

Efforts at the urban level to combat climate change are increasing over time more than 800 cities worldwide have set a goal to achieve carbon neutrality (IPCC, 2022). International city alliances have been established to reduce greenhouse gas emissions and eliminate their causes through joint commitments: the C40 Group and the Global Covenant of Mayors for Climate and Energy (GCoM). Some countries are striving to achieve ecological sustainability by prioritizing renewable energy sources. For example, in Switzerland, 54% of energy comes from renewable sources; Stockholm implements the “Green City” program focusing on green transport and buildings and Germany applies the Energiewende program and strict standards for transitioning to “green” energy and improving building energy efficiency (Smolkin, 2014).

2. Literature review

In the context of urban policy, the green economy is viewed as a system of measures and tools integrated into municipal and regional governance, aimed at greening economic activities, rational resource use, developing low-carbon infrastructure and improving urban environmental quality. In modern academic literature, cities are increasingly defined as key actors in the green transition, as they concentrate the main production, infrastructure and demographic resources (Bulkeley *et al*., 2014). Accordingly, the literature emphasizes a shift from traditional urban development models to the concepts of green cities, sustainable cities and resilient cities. The green economy in urban policy is implemented through strategic planning, climate action plans, the introduction of energy efficiency standards, the development of renewable energy sources and the greening of transport. As noted by Hodson and Marvin (2017), it is at the urban level that experimentation with innovative models of sustainable development is possible, which can later be scaled to the national level.

One of the key directions of green urban policy is the development of green infrastructure, including parks, green corridors, water bodies, green roofs and other elements of the natural environment. Research shows that green infrastructure provides not only environmental but also economic benefits, including reduced healthcare costs, climate adaptation and increased investment attractiveness of cities (Kabisch *et al*., 2016).

Significant attention in the literature is given to building energy efficiency, the development of public transport and the transition to electric mobility. Urban policy in this area is seen as an important tool for shaping a low-carbon economy and achieving climate goals (OECD, 2020). Contemporary studies highlight the growing role of the circular economy as an element of urban ecological resilience (Korhonen *et al*., 2018).

Several authors point to the risk of so-called “eco-gentrification”, where environmental improvements lead to rising housing costs and the displacement of socially vulnerable populations (Anguelovski *et al*., 2019). At the same time, empirical studies confirm that with an inclusive approach, green policy contributes to improved quality of life, the creation of green jobs and the reduction of social inequality (ILO, 2018).

Analysis of scientific sources shows that the green economy in urban policy represents a multi-level and interdisciplinary concept that combines environmental, economic and social goals. Modern research emphasizes the need for a comprehensive approach, institutional support and consideration of the social consequences of green transformations. Cities are seen not only as objects of regulation but also as active agents of the green transition.

3. Global experience

Major global metropolises are implementing serious measures to enhance ecological sustainability. In Paris, a comprehensive program for transitioning to renewable energy is underway, aiming to increase the share of renewable energy to 40% by 2030. Since 1996, the Berlin government, in cooperation with the Berlin Energy Agency, has implemented a special modernization mechanism to improve energy efficiency in public buildings. This mechanism is based on contracts between building owners and energy service companies. According to the contracts, the companies undertake the modernization and the costs are reimbursed by the building owners over 8-

12 years through savings on utility bills. Experience shows that annual energy consumption costs are reduced by 26% and GHG emissions decrease by 70,000 tons.

In São Paulo, 60% of consumed energy comes from renewable sources, primarily hydro and biomass (from sugarcane waste). In Beijing, a Mobility-as-a-Service (MaaS) platform is operational (Fedyanin *et al*., 2023). Through cooperation between city authorities and online cartographic services, various types of urban transport have been integrated. Since 2020, a program has been implemented within the platform to reward individuals who move around the city without private vehicles - using public transport, bicycles or on foot. The distances traveled by registered users are calculated and converted into carbon credits (a conditional unit reflecting the volume of reduced carbon footprint). These credits can later be used by users for public transport fares, discount coupons, online service subscriptions and similar purposes. According to a 2023 evaluation, over three years, 3.5 million people joined the program and carbon dioxide emissions were reduced by 400,000 tons.

In Moscow, green areas make up 50% of the city's territory. This achievement is due to the establishment of Specially Protected Natural Areas (SPNAs). According to the law, it is strictly prohibited to reduce the area of these zones or transfer them to private ownership.

Seoul's experience in household waste management is noteworthy. Since the 1990s, a tax system for waste disposal has been in place. In 2009, a new program was launched in cities for extracting metals from electronic waste. As part of the program, a financial incentive mechanism was introduced for students: income from processing mobile phones handed in by students is added to their scholarships. According to evaluations, between 2009 and 2021, this program helped reduce GHG emissions by 120,000 tons.

The "Demand Response and Peak Shaving" concept emerged in international energy management practices. It was first developed and widely implemented in the U.S. and European countries during the energy crises of the 1970s-1980s, when electricity grid overload became a problem. Operators such as PJM Interconnection, California ISO and New York ISO began implementing demand response and peak shaving programs. These programs offer financial incentives to enterprises and consumers to reduce energy use during peak hours, thereby lowering grid load and reducing the need for new power plants (https://www.pjm.com).

Since 2010, the European Union has formalized this model under the "Smart Grids and Demand Response Directive (2012/27/EU)". Germany, the Netherlands, Denmark, Sweden and France implement this program in large industrial enterprises and the municipal sector. Singapore's Energy Market Authority (EMA) has applied the "Demand Response Programme" since 2016. Japan expanded its peak shaving programs under the "Smart Energy Cities" project after the 2011 Fukushima incident (Energy Market Authority (Singapore), Demand Response Programme 2016 Report). In Azerbaijan, this model has not yet been fully implemented, but ideas such as "smart grids", "energy-saving measures" and "demand-side management" are already included in the Ministry of Energy's plans within the framework of the Energy Efficiency Strategy (2022-2030) and the Green Energy Program.

The World Bank and the International Energy Agency have implemented the "energy audits + pay-for-performance" project in industrial and commercial enterprises in various regions, achieving an average of ≈10% energy savings in the initial years. This model is used in cities like California, New York and Washington, primarily in projects aimed at improving building energy efficiency and conducting energy audits in industrial

enterprises. Measures include ISO 50001 certification, investment incentives (partial subsidies) and the implementation of energy management systems. Enterprises or buildings undergo energy audits to assess energy losses, equipment efficiency and savings potential. A baseline savings plan is developed, energy-saving measures are implemented (e.g., insulation, LED lighting, automated control) and actual savings (e.g., 15% annual energy reduction) are measured and verified. Payments from the state or energy companies are made only for the actual savings achieved (World Bank - Achieving Energy Efficiency in Buildings, 2025).

4. Main section

According to data from the State Statistics Committee (SSC), the most commonly used energy source for the production of thermal and electric energy in Azerbaijan is natural gas (98.4%). Of the electricity produced in Azerbaijan, 86% comes from fuel-based thermal power plants (TPPs), 6% from hydroelectric power plants (HPPs), 0.2% from wind power plants, 0.3% from solar power plants and 0.8% from waste incineration (Energy of Azerbaijan 2023, 2024).

The largest thermal power plant is the "Azerbaijan" TPP located in Mingachevir, with a production capacity of 2,400 MW. This plant emits more than 2 million tons of CO_2 into the atmosphere annually. Mingachevir also has a hydroelectric power plant with a capacity of 425 MW. In Baku and Sumgait, there are four TPPs of various capacities, with annual CO_2 emissions ranging from 1.61 to 3.51 million tons. In Shirvan, the "South" TPP emits between 0.01 and 0.1 million tons of CO_2 annually. In contrast, the cities of Ganja and Naftalan consume significantly less natural gas, with 82.2% of Ganja's and 62.6% of Naftalan's gas consumption attributed to households.

In 2022, Azerbaijan emitted a total of 59 million tons of greenhouse gases, accounting for 0.1% of global emissions. Electricity production reached 28.988 billion kWh, of which 24.218 billion kWh (83.5%) was generated in Baku, Sumgait, Shirvan and Mingachevir. These cities also accounted for 69% of total national electricity consumption (22.617 billion kWh) and naturally, the highest GHG emissions occurred there (Energy of Azerbaijan 2023, 2024).

Greenhouse gas emissions from each energy source are calculated using emission factors (National Report of the Russian Federation, 2012). For example, burning 1,000 cubic meters of natural gas releases 1.85 tons of CO_2 into the atmosphere. The table below shows CO_2 emissions from natural gas consumption in cities in 2022:

Table 1. CO_2 emissions from natural gas consumption in cities (2022)

	Baku	**Sumgait**	**Ganja**	**Naftalan**	**Mingachevir**	**Shirvan**
Natural gas million m^3	5315,4	1708,2	177,5	16,4	1263,3	1161,2
CO_2 eq. emissions tons	9833490	3160170	328375	30340	2337105	2148220

Source: SSC, Energy of Azerbaijan 2023; Abdalova (2025)

The table shows that approximately 31% (18 million tons) of national GHG emissions in 2022 resulted from natural gas consumption in cities. Of all primary energy products in the country, 47.5% came from crude oil (including gas condensate), 52.1% from natural gas and only 0.4% from renewable energy sources.

The Law of the Republic of Azerbaijan "On the Efficient Use of Energy Resources and Energy Efficiency", effective since July 1, 2022, addresses reducing energy consumption through energy efficiency measures. The Law "On the Use of Renewable Energy Sources in Electricity Production", adopted on May 31, 2021, also supports this direction. Clause 5 of the "Azerbaijan 2030: National Priorities for Socio-Economic Development" document, approved by Presidential Decree on February 2, 2021, emphasizes combating climate change and applying green energy principles across all sectors of the economy.

One of the main sources of GHG emissions in cities is the transport sector. As of 2023, Azerbaijan has 42,461 hybrid and 3,138 electric vehicles, along with 15 electric buses. This represents only 7.3% of passenger cars and about 0.1% of buses in Baku. The SSC considers only the metro as urban electric transport. In 2022, 208.7 million passengers used the Baku metro, accounting for 12.9% of all domestic passenger transport in Azerbaijan (Energy of Azerbaijan 2023, 2024).

Since electricity in Azerbaijan is primarily generated from fossil fuels, "clean" electric vehicles indirectly contribute to GHG emissions. However, the emission factor for natural gas (1.85 tons CO_2 per 1,000 m^3) is lower than that of gasoline (3.0 tons CO_2/t) or diesel (3.15 tons CO_2/t) (National Report of the Russian Federation, 2012).

On January 30, 2025, the President of Azerbaijan signed a decree approving the "2025-2030 State Program for the Improvement of Transport Infrastructure in Baku and Surrounding Areas". Earlier, on February 7, 2024, a decree was signed "On Promoting the Use of Electric Vehicles".

The most effective and realistic way to restore ecological balance is to expand green areas. Urban green spaces have significant potential for absorbing and storing carbon dioxide. The area of green spaces determines the city's ability to offset GHG emissions that cannot be eliminated through state measures within the climate agenda.

A working group at Lomonosov Moscow State University selected 20 megacities from developed and developing countries to assess their potential for mitigating climate change. Cities were evaluated across five areas, one of which was green space (measured as the percentage of green areas in the city). The average share of green areas is 33% in developed cities and 29% in developing ones. Beijing and Moscow stand out with 60% and 51% green coverage, respectively. Since the 1980s, China has celebrated National Tree Planting Day annually, during which citizens and leaders plant trees in their cities. As a result, Beijing's green space has more than doubled (Fedyanin *et al*., 2023).

Table 2. Share of green areas in Azerbaijani cities

	Baku	Sumgait	Ganja	Naftalan	Mingachevir	Shirvan
Specific weight of green areas, %	0,43	6,9	6,1	1,6	5,7	9,2

Source: (https://arxkom.gov.az/bakinin-bas-plani) Sumgait Landscaping Department, Google Maps

According to the Baku City Master Plan (https://arxkom.gov.az/bakinin-bas-plani), green areas (parks, squares and hybrid green corridors) covered 920 hectares in 2022, representing 0.43% of the city's area. The plan aims to expand this to 2,757.3 hectares by 2040, increasing per capita green space to 8.7 m^2. The plan includes extending the Baku Boulevard southward to Bibiheybat and eastward to Zykh. It's worth noting that official urban planning documents consider only the urbanized part of the city, excluding

industrial and desert lands from green zone potential (https://arxkom.gov.az/bakinin-bas-plani). Thus, the 920 hectares represent about 9% of the urbanized area.

In 2022, per capita public green space in Baku was 3-4 m^2, which is 2-3 times below the World Health Organization's minimum standard of 9 m^2. In 2020, Ganja joined the "Green City" Action Plan supported by the European Bank for Reconstruction and Development. The first phase of activities focuses on three areas: 1) solid waste management, 2) public transport renewal and 3) modernization of street lighting.

The "Azerbaijan 2030: National Priorities for Socio-Economic Development" document, approved by Presidential Decree on February 2, 2021, identifies "Clean Environment and Green Growth Country" as one of five national priorities. In line with this, efforts are underway to rehabilitate the environment and expand green spaces. On February 22, 2021, the Ministry of Energy of Azerbaijan and BP signed a Memorandum of Understanding to assess the potential and conditions for large-scale decarbonized and integrated energy and transport systems, including renewable energy projects in Azerbaijan's regions and cities. The memorandum envisions developing a "Master Plan" for decarbonization, covering clean energy projects, low-carbon transport, green buildings, waste management, clean industry, nature-based climate solutions, integrated partnerships and decarbonized energy and transport systems. In early 2024, "Azerenerji" JSC, in cooperation with "SOCAR Trading", applied to the "Gold Standard" and the "Global Carbon Council" (based in Qatar and Switzerland) to obtain carbon certificates for seven small hydroelectric power plants in the Kalbajar and Lachin districts. As a result, 45,000-50,000 tons of CO_2 emissions will be prevented annually (https://www.xalqqazeti.az/az/iqtisadiyyat/184778-kelbecer-lacin-ses-ler-karbon).

5. Conclusion

In Azerbaijan, 83.5% of electricity is produced in the cities of Baku, Sumgait, Shirvan and Mingachevir. These cities also account for 69% of national electricity consumption (22.617 billion kWh). This indicates a high level of centralization in both energy production and consumption, which poses risks to grid security and economic resilience. Therefore, reducing demand and smoothing peak loads should be prioritized. The fastest, most cost-effective and low-carbon way to mitigate the risks of centralized energy supply is through energy efficiency (EE) and demand-side management. Between 2022 and 2024, Azerbaijan has strengthened its legislation on energy use and EE and specific programs should now be implemented based on this foundation.

6. Recommendations

1. Pilot Projects in Cities:

Replace street lighting with LEDs in Sumgait and Mingachevir. Implement "energy audits + performance-based financial incentives" for industrial and commercial enterprises. Launch demand-side management projects.

Justification:

– In Los Angeles and many European cities, switching to LED lamps and smart control systems has led to 40-60% energy savings (UNEP/World Bank). LEDs are more efficient than HPS/halogen lamps and have lower operational and maintenance costs, with payback periods of 2-6 years.

– The World Bank and IEA's "energy audits + pay-for-performance" model has achieved ≈10% energy savings in industrial and commercial enterprises. Applying this model in Sumgait and Mingachevir's priority sectors (chemicals, energy) could enhance EE.

– In the U.S., PJM Interconnection LLC and European pilots have implemented "Demand Response + Smart Metering" systems. The principle: provide financial incentives for consumers to reduce load during peak hours, using smart metering and control systems to enable real-time responses. This reduces peak loads and improves grid stability. In Azerbaijan, such programs should first target large industrial and commercial consumers and later expand to retail users.

Financing: Initial funding should come from the State Investment Program and the Energy Efficiency Fund. International financial institutions, especially the World Bank (which has experience with regional projects), should also be involved.

2. Green Space Expansion in Baku:

Baku ranks among the lowest capitals of former Soviet republics in terms of per capita green space (3-4 m^2). WHO recommends a minimum of 9 m^2 per capita, with an optimal target of 50 m^2. Moscow's experience in expanding green zones and Beijing's transition to "clean" transport should be considered for replication.

3. Carbon Markets:

One of the economic incentives for reducing GHG emissions is participation in carbon markets.The phrase "pay for emissions" was cut off in the original document, but the context suggests a recommendation to develop mechanisms for monetizing emission reductions through carbon credits and trading platforms.

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