

Decarbonization and Circular Supply Chain Integration in a Transit Economy: A Six-Pillar Policy Assessment for Azerbaijan's Logistics Sector

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Abstract. Research on cutting carbon out of freight operations and research on the design of closed-loop supply chains (CLSC) have matured in parallel, with remarkably little contact between them. This paper asks where their combination yields something that neither delivers alone, and then reads the answer against a transit-dependent national economy. The work has two stages. An integrative review came first: queries covering January 2012 through March 2026 in Scopus, Google Scholar and the Core Collection of the Web of Science produced 412 records, from which 65 studies survived deduplication and full-text appraisal and entered the synthesis under a six-axis coding scheme. The second stage confronts that scheme with Azerbaijani strategy documents, agency reporting and branch statistics. Evidence drawn from modelled settings suggests that treating emission reduction and circular design as a single optimization problem lowers costs by as much as 31 per cent while cutting emissions by between 12 and 40 per cent, although such results hold only where financing channels, digital capability, managerial preparedness and geoeological reporting are already in place. At country level the assessment finds capital flowing into corridor infrastructure moving out of step with the instruments meant to govern emissions, and finds budgetary support unaccompanied by a carbon price unable to retain private green capital over time.

Keywords: decarbonization, closed-loop supply chain, sustainable logistics, green finance, geoeological monitoring, middle corridor, Azerbaijan

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Tranzit iqtisadiyyatında karbonsuzlaşdırma ilə qapalı dövrəli təchizat zəncirlərinin integrasiyası: Azərbaycanın logistika sektoru üçün altısütunlu siyasət qiymətləndirməsi

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Xülasə. Yük daşımalarında karbon emissiyalarının azaldılmasına dair tədqiqatlar ilə qapalı dövrəli təchizat zəncirlərinin (QDTZ) layihələndirilməsinə dair tədqiqatlar bir-birinə toxunmadan, paralel şəkildə formalaşmışdır. Məqalə bu iki istiqamətin birləşdirilməsinin ayrılıqda əldə edilə bilməyən hansı nəticəni verdiyini araşdırır və alınan cavabı tranzitə söykənən milli iqtisadiyyat kontekstində oxuyur. Tədqiqat iki mərhələdən ibarətdir. Birinci mərhələdə integrativ ədəbiyyat icmalı aparılmış, Scopus, Web of Science Core Collection və Google Scholar bazalarında 2012-ci ilin yanvarından

2026-cı ilin martına qədərki dövrü əhatə edən axtarış 412 qeyd vermiş, dublikatların çıxarılması və tam mətn qiymətləndirməsi sonrası 65 mənbə altı tematik ox üzrə kodlaşdırılaraq sintezə daxil edilmişdir. İkinci mərhələdə alınan sxem Azərbaycanın strateji sənədləri, beynəlxalq təşkilat hesabatları və sahə statistikası ilə tutuşdurulmuşdur. Modelə əsaslanan mənbələr göstərir ki, emissiyaların azaldılması ilə dövrəli layihələndirmənin vahid optimallaşdırma məsələsi kimi həlli xərcləri 31 faizədək, emissiyaları isə 12–40 faiz aralığında azaldır; lakin bu nəticələr yalnız maliyyə kanalları, rəqəmsal potensial, idarəetmə hazırlığı və geoekoloji hesabatlılıq mövcud olduqda özünü doğruldur. Ölkə səviyyəsində qiymətləndirmə dəhliz infrastrukturuna yönələn kapitalın emissiya idarəçiliyi alətləri ilə uzlaşmadığını, karbon qiyməti ilə müşayiət olunmayan büdcə dəstəyinin isə xüsusi yaşıl kapitalı uzunmüddətli saxlaya bilmədiyini aşkar edir.

Açar sözlər: *karbonsuzlaşdırma, qapalı dövrəli təchizat zənciri, dayanıqlı logistika, yaşıl maliyyə, geoekoloji monitoring, orta dəhliz, Azərbaycan*

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Introduction

A large share of the world's climate burden originates in the movement and storage of goods. The International Energy Agency places road haulage at close to 7 per cent of energy-related carbon dioxide emissions worldwide and at more than a third of what the transport sector as a whole releases (International Energy Agency (IEA), 2017). What was once read as an environmental statistic now carries commercial and legal consequences under the temperature limit agreed in Paris. Carbon adjustment at the European Union border, mandatory sustainability disclosure and the conditions written into the contracts of international buyers have together turned the emission profile of a consignment into a precondition of market entry.

Two bodies of scholarship have grown up in response, and they have grown up apart. The first studies the instruments of emission reduction: electrified fleets, better routing, energy performance in warehouses, digital control systems (McKinnon & Piecyk, 2012; Lu et al., 2023). The second builds mathematical models of closed-loop supply chains, designs reverse logistics networks and asks how materials return to productive use (Govindan & Soleimani, 2017; Lozano-Oviedo et al., 2024). Each is methodologically well equipped. What lies between them is thinner. The emissions that reverse flows themselves generate, or the way spending on emission reduction reshapes decisions about circular design, are questions neither literature has claimed as its own.

For Azerbaijan the gap has a concrete counterpart. The second Nationally Determined Contribution, filed in 2023, undertakes a 40 per cent cut in greenhouse gases relative to 1990 by mid-century, and pairs this with a 2030 objective under which renewables would supply 30 per cent of installed generating capacity (2023; IEA, 2022). Transit activity has expanded quickly over the same years. Volumes moving across the Caspian on the Middle Corridor climbed from something near 0.5 million tons before 2022 to 4.1 million tons in 2024, a yearly rate above 63 per cent (Conradi, 2026), while transit cargo moving across Azerbaijani territory as a whole added 8 per cent in that year and reached 114.5 million tons (Oxford Business Group, 2026). The tension is easy to state. More transit is desirable economically, yet unless the machinery for managing emissions grows at a comparable rate, the additional tonnage sits awkwardly against the climate pledge. Work published earlier by the

present authors found the institutional link between corridor capital and green investment mechanisms to be a weak one (Abdulhasanova, 2025; Abdulhasanova & Abdulhasanov, 2026).

Three questions structure what follows. By what mechanisms does the joint optimization of emission reduction and circular design actually operate? What has to be true organizationally, financially and territorially before that integration produces an effect? And how large is the measurable advantage under Azerbaijani conditions? Two contributions are intended. Review work in this field has kept its analytical categories close to operations and management; the scheme used here adds ecological accountability and the regional macroeconomic setting to that inventory. The scheme is then carried, for the first time, into the corridor economy of Azerbaijan, where each pillar is assessed for where the country now stands, what holds it back and which policy instrument deserves precedence. That country stage is what separates the present paper from the conceptual synthesis the authors published earlier (Abdulhasanova et al., 2026a).

Methods

Research design. The design is mixed and sequential. A review of the literature forms the first stage; the second takes the framework that emerges from it and tests that framework against secondary Azerbaijani data. An integrative approach was chosen because the material is heterogeneous in method, with optimization models sitting beside engineering assessments, policy analysis and institutional research. Meta-analysis in the quantitative sense cannot be applied where dependent variables and units of measurement share no common basis.

Search and selection. Retrieval was carried out in three databases — Scopus, Google Scholar and the Core Collection of the Web of Science — with the corpus limited to English-language work published from January 2012 onward and closing in March 2026. Three Boolean strings structured the retrieval: (1) ("reverse logistics" OR "closed-loop supply chain") AND ("carbon emission" OR "green logistics" OR "decarbonization"); (2) ("green supply chain" OR "sustainable logistics") AND ("framework" OR "optimization"); (3) ("geoecological monitoring" OR "IoT scheduling" OR "building energy") AND ("supply chain" OR "logistics"). Retrieval yielded 412 records, distributed 168, 142 and 102 across the three sources respectively. Once 87 duplicates had been withdrawn, 325 items remained; screening of titles and abstracts brought the set down to 142 studies read in full. To be included, a study had to be peer-reviewed, to engage directly with circular chain design or freight decarbonization, and to report either a measured result or a framework. Sixty-five works passed these filters and form the corpus of the synthesis.

Coding and derivation of the pillars. Coding of the 65 sources ran along six thematic axes. Three of them — the technological layer, the architecture of circular design and the instruments of policy — reproduce the operational and governance division that the field's principal reviews have established (Govindan & Soleimani, 2017; Genovese et al., 2017). The other three axes concern whether integration is feasible at all: what the organization must have in place, how ecological consequences are accounted for, and what the surrounding regional economy permits. Existing frameworks treat this second group thinly (Lozano-Oviedo et al., 2024). Nothing further emerged during coding with enough internal coherence to warrant a seventh axis.

Country-level stage and limitations. Applying the framework to Azerbaijan meant working with official documents, reporting by international organizations and branch statistics. Every pillar was assessed on three parameters: the present state of affairs, the binding constraint and the instrument that deserves priority. Each assessment was cross-checked against empirical studies the authors have published on Azerbaijan (Aliyev et al., 2024; Abdulhasanova et al., 2026c; Ahmadova et al., 2026). Three limitations deserve plain statement. An integrative review rests on qualitative judgement and

cannot be declared free of selection bias. Restricting the corpus to English leaves part of the regional scholarship outside it. And the country stage draws on secondary material rather than on fieldwork of the authors' own.

Results

Mechanisms of emission reduction. Six families of mechanism recur across the reviewed material. Table 1 sets out how each works and what results have been reported for it.

Table 1

Mechanisms of emission reduction in freight activity and their reported outcomes

Strategy	Operating logic	Reported outcome	Source
Fleet electrification	Battery-electric vehicles drawing power from renewable generation	Lifecycle emissions lower by roughly 30%	Lu et al. (2023)
Thermal retrofit of buildings	Internal insulation reducing heat transfer through the envelope	Marked energy savings in warehouses and terminals	Hajiyev et al. (2025)
AI and IoT scheduling	Task allocation by a scheduler coupling fuzzy inference with evolutionary search	Computational energy demand and latency both fall	Akana et al. (2025)
5G and edge computing	Routing decisions taken in real time under very low latency	Latency down by as much as 85%	Wang & Wang (2025)
Green financing	Blended vehicles that capitalize assets in green logistics	Public funds attracting private capital at considerable leverage	Abdulhasanova (2025)
Shift between modes	Investment in rail that draws cargo away from the road	Journey times cut by up to 12%	Asgarova & Abbasova (2024)

Source. Prepared by the authors on the basis of the reviewed studies.

Taken singly, none of these mechanisms carries far enough. How much electrification saves depends on how carbon-intensive the grid is, and in the Azerbaijani case that intensity is governed by the renewables target for installed capacity. An exercise applying the Toda–Yamamoto procedure to Iceland and Azerbaijan reported a positive and statistically significant link running between renewable consumption and growth (Aliyev et al., 2024). Spending on electrification therefore rests on a productivity case as much as an environmental one.

Typologies of closed-loop modelling. Five principal types organize the modelling literature reviewed here. Multi-objective formulations weigh profit, emissions and social welfare at once through Pareto optimization (Mohtashami et al., 2020). Stochastic and robust programming handles uncertainty in demand and in return flows (Sardar et al., 2025). Game-theoretic constructions coordinate the choices of competing actors through Nash and Stackelberg equilibria (Song et al., 2026). Reward-penalty formulations build regulatory incentives aimed at maximizing collection rates (Li et al., 2021). IoT-integrated models feed real-time data back into operations to lower energy use while raising recovered

volumes (Sorooshian et al., 2024; Akana et al., 2025). The categories do not exclude one another, and recent contributions combine them with growing frequency.

Quantified outcomes of integration. Table 2 collects what modelled studies report once the two problems are solved together.

Table 2

Reported gains from treating emission reduction and circular design as one problem

Object of study	Cost saving	Emission saving	Method applied	Source
Routing in a green cold chain	up to 31%	15–25%	Multi-objective routing solved by metaheuristics	Zheng et al. (2025)
Circular chain for EV batteries	15–22%	25–35%	IoT-based integration	Sorooshian et al. (2024)
Power battery closed loop	18–28%	15–22%	Stackelberg game	Song et al. (2026)
Petrochemical chain	10–15%	10–15%	Robust integrated programming	Sardar et al. (2025)

Source. Compiled by the authors from the reviewed literature.

Caution is needed in reading these numbers, which come from studies that differ in method. They convey the order of magnitude that becomes attainable under modelling assumptions and should not be mistaken for pooled statistical estimates. In practice the reported gains erode in proportion to whatever weaknesses exist in institutional quality and in the data infrastructure available.

Six pillars and what they show for Azerbaijan. Six pillars emerge from the synthesis, and they fall into two groups. The first group establishes whether integration is technically conceivable: it covers the technological layer, the architecture of circular network design and the instruments of policy. The second group decides whether integration can be executed at all: it covers organizational readiness, geoecological accountability and the regional macroeconomic setting. The central claim of the framework is that technical solutions across the first group leave integration a paper exercise for as long as the conditions in the second group go unmet. Table 3 carries the pillars into the Azerbaijani case, and this stage is where the study's own contribution lies.

Table 3

The six pillars applied to the logistics sector of Azerbaijan

Pillar	Where the country stands	Binding constraint	Instrument deserving priority
Technological layer	Renewables target of 30% of installed capacity by 2030; customs procedures being digitalized	Electric traction practically absent from heavy freight; no charging infrastructure	Pilot charging network along the corridor; digital platform for freight management

Pillar	Where the country stands	Binding constraint	Instrument deserving priority
Architecture of circular design	Recycling activity concentrated in the metal and paper segments	Extended producer responsibility only partly operational; reverse flows go unrecorded	Statutory collection targets for priority product groups
Instruments of policy	Climate commitment articulated in the NDC; the toolkit rests mainly on budget expenditure and tax relief	With no carbon price in place, fiscal spending has limited power to crowd in private green investment	A carbon price signal added alongside the existing fiscal incentives
Organizational readiness	Training capacity in logistics is widening	Departure of skilled labour, together with the drag that digital information overload places on productivity	Targeted vocational training; protocols governing the use of digital tools
Geoecological accountability	Large infrastructure projects undergo environmental impact assessment	Neither the retreating level of the Caspian nor the mined territories enter logistics planning	Monitoring of ecological conditions maintained continuously along the corridors
Regional macroeconomic setting	Transit volumes climbing; corridor prospects opening for Nakhchivan	High transport costs and limited scale economies under exclave conditions	A differentiated incentive regime that accounts for regional disparities

Source. Authors' assessment, drawing on Ministry of Ecology and Natural Resources of the Republic of Azerbaijan (2023), IEA (2022), Oxford Business Group (2026) and the authors' earlier empirical work.

Discussion

What fiscal policy cannot do by itself. Panel econometric work carried out by the present authors indicates that public environmental expenditure pulls in private green investment on a lasting basis only when a carbon pricing mechanism accompanies it; with no price signal in place the crowding-in effect weakens, and certain specifications turn it into crowding out (Abdulhasanova et al., 2026c). The reading for logistics follows directly. Warehousing that meets green standards, electric fleets and facilities for reverse flows are all long-payback assets, so financing them out of grants and concessional credit alone caps the achievable volume at whatever the state budget permits. This aligns with earlier analysis, which located the structural obstacles to mobilizing green capital in Azerbaijan in subsidized fuel, an underdeveloped set of green financing instruments and thin risk mitigation (Abdulhasanova, 2025), and with work on investment priorities which records a persistent distance between what is declared a priority and where money actually goes (Ahmadova et al., 2026).

The productivity paradox in digitalization. The literature treats digital instruments as the principal accelerator of emission reduction, and a scheduling framework that pairs fuzzy inference with an evolutionary search algorithm supports the claim on the energy side for fog and cloud networks

(Akana et al., 2025). Their organizational effect is more ambiguous. Empirical analysis for Turkey found that an abundance of information and dependence on digital tools both weigh negatively on worker productivity (Abdulhasanova et al., 2026d). Once the volume of real-time data outruns what the operator can process, decision quality falls away and the expected return on the technology investment declines with it. Deployment therefore needs filtering protocols and a decision-support architecture designed on purpose rather than assembled by default.

Customs efficiency and the environmental side of corridor logic. Border procedure rarely appears in the decarbonization literature as an emission factor, yet the emissions released at a crossing rise in step with the count of vehicles left idling while they wait. Analysis of how customs efficiency relates to logistics performance in Azerbaijan established that shorter procedural times raise trade volume (Abdulhasanova et al., 2026b); the same result admits an environmental reading, since digitalizing document flow is among the few measures that ease trade and cut emissions at once. Examination of the Middle Corridor alongside the Zangezur Corridor points in the same direction: the choice of corridor determines the emission outcome not through distance and tariff alone but through the modal composition it implies (Abdulhasanova & Abdulhasanov, 2026).

The geoecological dimension. Using monitoring models to trace how transport infrastructure alters land use is a relatively recent line of enquiry (Mamonov et al., 2024), and it acquires particular weight in Azerbaijani conditions. The Caspian Sea has been losing level at rates averaging as much as 30 centimetres a year since 2020, and ferry operations have already felt it: traffic in rail tank cars on the Baku–Kuryk route contracted by 22 per cent and wagon traffic by 10 per cent (Conradi, 2026). Far from being a supplementary variable, the geoecological one belongs at the centre of logistics planning, because any loss of reliability in the maritime crossing pushes cargo onto overland routes and shifts the emission balance with it.

Organizational and regional preconditions, with the evidence that cuts the other way. Whether integration happens is decided by organizational readiness rather than by technology. Converting innovation potential into economic results depends on the quality of management (Abdulhasanova & Aliyeva, 2024), and in logistics that question is tied to labour mobility as well, because a departure of qualified staff slows the pace at which new technology is absorbed (Abdulhasanova, 2024). The sixth pillar insists that differences inside the country be taken into account. Transport costs run higher in the Nakhchivan Autonomous Republic because of its exclave position, and scale economies are correspondingly harder to reach (Ahmadova et al., 2018); a subsidy rate large enough to redirect an investment decision in the central districts therefore fails to cover the additional expense incurred there. The integration thesis is not beyond dispute in any case. Multi-objective models are complex, and that complexity generates additional operating costs wherever institutional capacity is weak, which offsets part of the efficiency gain (MahmoumGonbadi et al., 2021). Social sustainability is likewise thin on theory, given how rarely employment indicators are admitted into the objective function.

Conclusion

Freight decarbonization and the design of closed-loop chains have been treated here as lines of development that condition one another rather than as competing alternatives. Synthesis of 65 sources produced a framework of six pillars, gathering into one analytical scheme the technological layer, the architecture of circular design, the instruments of policy, organizational readiness, geoecological accountability and the regional macroeconomic setting. Three findings deserve emphasis. Joint optimization lowers costs by as much as 31 per cent and cuts emissions by 12 to 40 per cent under modelling assumptions, yet these magnitudes are sensitive to institutional quality. The last three pillars, thinly represented in existing review work, turn out to be exactly the ones that bind in practice.

And fiscal instruments applied in the absence of a carbon price do not hold private green investment over time. Four practical priorities follow for Azerbaijan. An emission criterion should enter the formal appraisal of investment decisions concerning corridor infrastructure. Digitalization of customs and documentation should be treated as an instrument of emission reduction as much as of trade facilitation. Blended finance structures should be built for green logistics assets with long horizons. And geoecological monitoring along corridor routes should be placed on a permanent footing.

The limits of the exercise are plain enough. Review work of this kind depends on selective judgement; the quantified figures are not pooled statistical estimates; the framework still awaits empirical validation; and the country reading was assembled from secondary material. Three directions suggest themselves for further work: turning the framework into a structured survey instrument for use across the South Caucasus and Central Asia; feeding geoecological monitoring data into closed-loop optimization models; and building emission accounts at the level of the corridor, a move that would relocate the unit of analysis from the firm to the corridor itself.

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