SUSTAINABLE LAST-MILE DELIVERY TECHNOLOGIES IN REGIONAL PERSPECTIVE AND POLICY-MAKING: INPUT-OUTPUT ANALYSIS

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Abstract. The research examines the economic impacts of adopting sustainable last-mile delivery technologies in the EU, using an input-output analysis. The research focuses on technologies used by postal and courier companies (CPA H53) across different EU countries. The aim is to model the economic effects on other industries if the existing sustainable technology is applied instead of the existing. Germany, France, Sweden, the Netherlands, and Denmark have greener Postal and courier services (CPA H53), utilizing more Telecommunications (CPA J61), Computer programming (CPA J62_J63), and Warehousing services (H52) compared to Latvia, Estonia, and Lithuania, where rival services (H53) are more prevalent. Poland was considered but rejected due to data confidentiality as too few companies operate. The modelling results of regional technological convergence claim that if the companies overtake the existing technology in another country, then, in the case of Latvia, if the technologies applied in Estonia are overtaken, then the existing demand results in larger sectoral output (0.1%), largest decline is for Services auxiliary to financial and insurance services (K66) (-10.5%). However, if the companies in Latvia overtake the existing Lithuanian technology, it results in smaller and more efficient economic activity (-0.1%), and less Services auxiliary to financial services (-10.9%), and air transport (-4.7%), but demands more paper production (+4.6%) and Printing services (+4.1%). The findings are valuable for the national and EU policymakers to assess the potential impacts of technological convergence in regions partially facilitated by the European Green Deal.

Keywords: sustainable transport, last-mile delivery, regional development, input-output analysis.

Introduction

The transition to sustainable last-mile delivery technologies is a decisive component of achieving environmental and economic sustainability within the European Union (EU). As e-commerce and urbanization continue to expand, the demand for efficient and sustainable delivery solutions becomes increasingly significant. The research examines the economic impacts of adopting sustainable last-mile delivery technologies in the EU, using an input-output analysis. Economical, technological, environmental and social aspects of last-mile delivery have been intensively examined from various aspects as examining the impact of collaboration in last-mile food deliveries [1], financial and environmental advantages of adopting lower emissions technologies as electric vehicles in delivery services [2], the fiscal and taxation aspects of applying tax discounts to alternative transport [3], examining the sustainable last-mile delivery in the growing e-grocery sector [4].

The input-output approach is used in many combinations on various topics, as assessing the economic impacts of extreme policy measures [5], COVID-19 [6], extreme nature as floods [7], impact of certain hardly coverable economic activity (as connected and autonomous vehicle industry in Korea [8]). Regarding transport, input-output approach is used for modelling the benefits of productivity-enhancing innovations within a real interregional input–output framework [9], assessing the impact of transportation on sustainable development [10], economic effect of investments in the transport and logistics sector[11], production costs reduction due to the adoption of longer and heavier vehicles in transportation [9]. Studies also examine not only national but also regional and local effects [12; 13].

There is no one standardized indicator or index accepted and used for performing international comparisons on how green transport services are in the EU. A study of 27 EU member states examining the share of renewable energy in total energy consumption in the transport sector claims that the best results were in Sweden, Finland, the Netherlands, Luxembourg, and Estonia [14]. Some studies have focused on evaluating and ranking the EU Climate and Energy policies as transport is one of the core targets to meet climate neutrality and emission reduction goals. The study on countries ranking claims that Sweden, Denmark, Austria, Ireland, Finland, Latvia, and Lithuania are admitted to performing the best amid the EU [15]; another study argues that the best European Green Deal performance was in the Netherlands, Sweden and Ireland [16]. The Nordic countries are particularly notable for their consistency and demonstrate robust strategies for energy sustainability and effective policy frameworks [17].

While existing studies provide valuable insights into the performance of individual countries, there is a lack of comprehensive analysis on the economic effects of adopting sustainable last-mile delivery technologies across different regions. This research aims to fill this gap by modelling the direct and indirect economic impacts on various industries when existing and already applied sustainable technology is implemented in postal and courier services.

The aim is to model the economic effects on other industries if the existing sustainable technology is applied instead of the existing technology. The primary focus of this research is on technologies within the European Union (EU) and utilizing an input-output analysis for modelling.

Explicitly, the study aims to model the direct and indirect economic effects on various industries when existing sustainable technologies are implemented in place of current practices. Technological, environmental, including emissions and psychological related to human decision-making and human behaviour and habit change, aspects are outside the scope of this research. This research focuses on technologies employed by postal and courier companies (CPA H53) across different EU countries, with a particular emphasis on Germany, France, Sweden, Latvia, Estonia, and Lithuania. The scope of countries covered is determined by both the data availability and comparability of the results. The findings of the research are potentially valuable for regional, national and also the EU level policymakers and stakeholders due to new perspective and arguments on examined technological shifts. The European Green Deal has high target levels, and decisions and actions taken in regional policy-making can affect the planned and expected results in the next decade or longer time.

Materials and methods

The research examines the economic impacts of adopting sustainable last-mile delivery technologies in the EU, using an input-output analysis. The research focuses on technologies used by postal and courier companies (CPA code: H53) across different EU countries. Statistical Classification of Products by Activity (CPA) is applied by Eurostat to classify products (covering goods and services) within the European Union, and CPA is in line with the economic activities defined by the Statistical Classification of Economic Activities (NACE) in the European Community. Hence product-by-product input-output table sets meet CPA classification, and industry-by-industry meet NACE classification. If a concept of homogenous industries is applied, then the certain NACE industry produces only the accompanying CPA product category. However, in the EU, this concept is more theoretical, and, nowadays, fewer countries apply it for input-output data sets, focusing on one product-by-product or industry-by-industry perspective or, in relatively minor cases, covering both at the time. For example, in Latvia, more than 2 decades ago, the input-output data set was according to homogenous industries, and also, this is discontinued, and the product-by-product approach has been applied for a relatively long time.

The research primary focus is on Latvia. However, the research also examines the EU countries with product-by-product symmetric input-output data set, as Belgium, Czechia, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Hungary, Austria, Portugal, Slovenia, Slovakia, Sweden. Poland was considered but rejected due to data unavailability in the comparative input-output data set caused by data confidentiality attributable to too few companies operating in H53. On the performed literature review basis, as benchmark countries with green and sustainable transport sector, including postal and courier services, were considered Sweden, Finland, the Netherlands, and Denmark as they are amid countries with robust energy policies and more sustainable current performance amid the EU. As Finland, the Netherlands and Denmark have industry-by-industry, but not product-by-product dimensions for input-output data sets, then Sweden is selected as the benchmark country. Additionally, for international comparison there are selected France and Germany (to represent large economies) and Latvia, Lithuania, and Estonia (for regional and economy-size comparability), and Sweden.

The symmetric input-output data for 2020 is used; only a few countries have published data sets on more recent periods as 2021 and 2022. The symmetric input-output tables demand additional time to be compiled and published; the mandatory requirement is to publish within 3 years after the period and it is not rarer than every five years; many EU countries publish every five years.

The steps taken for evaluation and modelling are as follows.

1. The in-depth analysis of core elements of direct costs of all EU countries with available data. And international analysis of updated H53 input coefficients (covering 19 EU countries), justification of selected benchmark countries for regional convergence and also the re-assessment of the selected benchmark country for greener already existing last-mile delivery technologies.
2. Latvia's input-output model [18] (demand-driven model) update and improvements to the altered model (overtaken direct costs coefficients and also value added coefficient) and model calibration for 2020 data.
3. Modelling regional technological convergence if the postal and courier services (H53) in Latvia overtake the existing technology from Estonia, other direct input coefficients of 63 products are hold constant (only H53 is changed), resulting in sectoral impact on 64 economic activities output, value added and final demand (Scenario 1). The main focus is paid to the value added indicator. Results are computed in absolute values, and relative changes in percentage are computed.
4. Modelling regional technological convergence with the existing technology in Lithuania (Scenario 2).
5. Modelling the impact of overtaking the most recent postal and courier technology in Sweden in 2022 (Scenario 3).
6. The bottom-up approach is used, aggregating values of 64 into 20 groups of economic activity as a regional (regions) bridge matrix is not available for 64 economic activities. Then the computations of absolute values and relative impact on regional value added by 5 statistical regions.

The research methodology includes classic input-output analysis based on classic identities that total supply is identical to total use. Direct input coefficients illustrate the input vector of a specific economic sector, i.e. what and how many products of other sub-sectors and payments for labour, capital and other production resources are required to produce one unit of the specific sub-sector's products, representing the technological requirements (A_{ij}) (see Formula (1)):

$$A_{ij} = \frac{X_{ij}}{X_j}, \tag{1}$$

where X_{ij} – intermediate consumption of *i* products by *j* product.

By comparing direct input coefficients in various countries applying the same methodology, the variances in technologies and technological requirements are being identified. Additionally, the coefficients of added value v_j can be computed (see Formula (2)).

$$v_j = \frac{VA_j}{X_j}, \tag{2}$$

where VA_j – added value of *j* product.

The modelled output is computed by (see Formula (3)):

$$\hat{X}_i = \left(I - A_{ij}\right)^{-1} * FD_i, \tag{3}$$

where $\hat{X}_i$ – computed (modelled) output of *i* product;
$(I - A_{ij})^{-1}$ – total requirements (*Leontief inverse*) matrix;
FD_j – net final demand for i product.

The modelled value added is computed using the reverse computations applying Formula (2), using the computed output and coefficients of added value. Then, the value-added aggregated into 20 major economic activities, and then, using the bridge computations, the regional development for 5 statistical regions was computed. The grammar check was partially assisted by Grammarly and Copilot.

Results and discussion

Postal and courier services in the EU generated 0.44 EUR cents per output of 1 euro, on average, in 2020. There is a relatively minor difference between the EU average and the Euro area (see Table 1). The range of coefficients of added value v_j illustrates the diversity of postal and courier services in 19 EU countries covered by the symmetric product-by-product data set. The extremely high value-added per one unit produced was in Croatia (0.855), which was mainly determined by the extremely high share of

compensation of employees (0.513) and operating surplus and mixed income (0.334) per one unit produced. Hungry, Ireland, Cyprus, Greece, and France have the coefficients of added value in the range of 0.630 and 0.536, however, there is no evidence to claim common patterns regarding relative operating surplus and compensation of employees to output. The two-sample t-test results indicate a statistically significant difference between the means of the first group of countries and the rest countries. The one-tailed p-value is 0.0051, and the two-tailed p-value is 0.0102, both of which are below the critical values, confirming the significance of the observed differences. However, there is no statistically significant difference between the second and the third group that are created splitting the rest into 2 parts. The second group of countries that share close to the average – Slovenia, Sweden, Austria, Portugal, Lithuania, Czechia, and Slovakia – also have a more homogenous distribution. The third group – Spain, Latvia, Belgium, Germany, Italy, and Estonia – has notably higher relative use of intermediate inputs and hence smaller value added per unit of output. Value added per unit of output (coefficients of added value) in postal and courier services are unstable over time; for example, in Sweden, the coefficient has declined from 0.512 in 2019 to 0.409 in 2022 (in 2021, 0.477 (see Table 1)).

Table 1

Direct cost coefficients of postal and courier services by major elements in 2020

Country	Intermediate consumption	Operating surplus and mixed income, gross	Compensation of employees	Value added, gross
EU-27	0.540	0.093	0.343	0.437
Euro area	0.543	0.091	0.343	0.434
Croatia	0.145	0.334	0.513	0.855
Hungary	0.313	0.156	0.465	0.630
Ireland	0.411	0.085	0.457	0.567
Cyprus	0.429	0.050	0.498	0.543
Greece	0.424	0.211	0.367	0.540
France	0.416	-0.134	0.657	0.536
Slovenia	0.438	0.081	0.473	0.523
Sweden*	0.512	0.072	0.341	0.477
Austria	0.551	0.101	0.321	0.439
Portugal	0.542	0.082	0.353	0.438
Lithuania	0.503	0.127	0.309	0.435
Czechia	0.535	0.077	0.389	0.432
Slovakia	0.574	0.096	0.318	0.418
Spain	0.565	-0.025	0.455	0.417
Latvia	0.588	0.078	0.310	0.391
Belgium	0.560	0.081	0.314	0.386
Germany	0.604	0.093	0.284	0.376
Italy	0.615	-0.034	0.385	0.357
Estonia	0.657	0.104	0.248	0.336

*Data on 2021; no data on 2020 available in Eurostat. Source: the author's calculations, on the basis of [19]

Germany, France, and Sweden are considered to have greener postal and courier services (PA H53), the analysis of the direct costs elements in these countries highlights there are utilized more Telecommunications (J61), Computer programming (J62_J63), and Warehousing services (H52) compared to Latvia, Estonia, and Lithuania, where rival services (H53) are more prevalent.

The modelling results of regional technological convergence claim that if the companies overtake the existing technology in another country then, in the case of Latvia, if the technologies applied in Estonia are overtaken (Scenario 1), then the existing demand results in larger overall nationally (0.1%), largest increase is for own services (postal and courier services (H53); by 12.1%), followed by air transport (H51), publishing services (J58) and printing services (C18) (see Table2). The modelled largest decline is for Services auxiliary to financial and insurance services (K66) (-10.5%), followed by a

notable gap in Textiles, wearing apparel, leather and related products (C13-C15) (-0.3%) and Rental and leasing services (N77) (-0.2%).

Table 2

Modelling results on the largest demand increase in the case of regional technological convergence in Latvia (Scenario 1)

Product/Service (CPA code)	Change, in% (compared to the pre-scenario situation)
Postal and courier services (H53)	12.1%
Air transport services (H51)	3.3%
Publishing services (J58)	1.3%
Printing and recording services (C18)	1.2%
Basic metals (C24)	1.1%
Repair and installation services of machinery (C33)	1.0%

Source: the author's calculations; listed results above 1%

Further examination of the modelling results reveals due to the large share of imported products and smaller value added per one unit of output the modelled actual increase of value added is notably smaller, only 0.01%. The regional sectoral impact in Latvia, according to statistical regions, reveals only minimal impact both due to the small relative size of the modelled activity (Postal and courier services accounted for 0.3% of value added) and relatively minor modelled technological shifts. The summary results on the Latvian regional development by statistical regions are summarised in Table 4.

However, if the companies in Latvia overtake the existing technology in Lithuania (Scenario 2), it results in smaller and more efficient economic activity (-0.1%), and less Services auxiliary to financial services (K66) (-10.9%), Air transport (H51) (-4.7%), Chemicals and chemical products (C20) (-0.9%), Warehousing and support services for transportation (H52) (-0.7%), Rental and leasing services (N77) (-0.6%), but demands more paper production (+ 4.6%) and Printing services (+ 4.1%) (see Table 3).

Table 3

Modelling results on the largest demand increase in the case of regional technological convergence in Latvia (Scenario 2)

Product/Service (CPA code)	Change, in% (compared to the pre-scenario situation)
Paper and paper products (C17)	4.6%
Printing and recording services(C18)	4.1%
Postal and courier services (H53)	1.9%
Security and investigation services; office administrative, office support services (N80-82)	0.6%
Services furnished by membership organisations (S94)	0.3%

Source: the author's calculations; listed results above 0.3%

The study [18] in 2024, modelling the introduction of the existing technology in postal and courier services in Latvia from a benchmark country (Sweden) and using the latest data set of 2019 (available at that research implementation timeframe), argued a minimal but negative impact of 0.06% decline in total value added. However, the updated model using the data of 2022 for the Swedish postal and courier services shows sensitivity to technological direct cost coefficients and value added coefficient change, and the modelled effect to the total output and also value-added increase of 0.02% (see Table 4). The modelled scenarios indicate that Riga's statistical region is more adversely affected due to the high share of service activities.

Definitely, more efficient technologies require digital and autonomous solutions that arise with legal aspects and the need for a regulatory framework [20], also environmental effect and emissions [20].

The findings are valuable for the national and EU policymakers to assess the potential impacts of technological convergence in regions partially facilitated by the European Green Deal.

Table 4

Modelling results on regional impact in the case of regional (value added change, in% compared to pre-scenario situation) in Latvia

Scenarios	Latvia	Riga	Vidzeme	Kurzeme	Zemgale	Latgale
Scenario 1	0.01%	-0.01%	0.04%	0.03%	0.05%	0.02%
Scenario 2	-0.03%	-0.06%	0.03%	0.04%	0.03%	0.03%
Scenario 3**	0.02%	0.01%	0.03%	0.06%	0.02%	0.04%

Source: the author's calculations; used the updated input-output data set on Sweden in 2022, statistical regions plotted

Conclusions

1. The modelling results show sector-specific impacts as different sectors perform varying from technological convergence. For example, postal and courier services benefit significantly from adopting Estonian technologies (Scenario 1) (+12.1%), while services auxiliary to financial and insurance services face extensive declines (-10.5%).
2. The modelling results highlight the potential efficiency gains of adopting Lithuanian technologies (Scenario 2) leading to a more efficient economic activity.
3. Due to the relatively minor share of postal and courier services in the economy (0.3% of value added), the overall regional impact in Latvia is minimal, indicating that technological convergence and shifts towards green and sustainable practices have no drastic impact on regional economic dynamics.
4. The identified sensitivity to data updates highlights the importance of using current and accurate data in economic modelling, policy-making and decision-making.
5. These findings provide valuable insights for local, national, regional and the EU policymakers, advocating that targeted strategies may be needed to mitigate negative impacts on certain sectors while promoting growth in others. This is particularly relevant in the context of the European Green Deal, which aims to facilitate technological advancements and sustainable development.

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Author contributions

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References

[1] Aktas E., Bourlakis M., Zissis D. Collaboration in the last mile: evidence from grocery deliveries, Int. J. Logist., 2020, pp. 1-15. DOI: 10.1080/13675567.2020.1740660
[2] Scedrovs A., Mendzins K., Barisa A., Feofilovs M. Electrifying the last mile delivery by Eco-efficiency analysis: Case study of Latvia, Environ. Clim. Technol., vol. 28, no. 1, 2024, pp. 367-378. DOI: 10.2478/rtuect-2024-0029
[3] Juruss M., Smite-Roke B., Nesterenko I. Reducing externalities of last mile delivery through taxation, 23rd International Scientific Conference Engineering for Rural Development Proceedings, 2024. DOI: 10.22616/ERDev.2024.23.TF233
[4] Tudisco V., Perotti S., Ekren B. Y., Aktas E. Sustainable e-grocery home delivery: An optimization model considering on-demand vehicles, Comput. Ind. Eng., vol. 201, no. 110874, 2025, p. 110874. DOI: 10.1016/j.cie.2025.110874

[5] Reissl S. et al. Assessing the economic impact of lockdowns in Italy: A computational input-output approach, Ind. Corp. Chang., vol. 31, no. 2, 2022, pp. 358-409. DOI: 10.1093/icc/dtac003
[6] Reissl S., Caiani A., Lamperti F., Ferraresi T., Ghezzi L. A regional input-output model of the {COVID-19} crisis in Italy: decomposing demand and supply factors, Econ. Syst. Res., vol. 36, no. 1, 2024, pp. 100-130. DOI: 10.1080/09535314.2023.2213394
[7] Di Noia J., Caiani A., Cesarini L., Arosio M., Monteleone B. A high resolution input-output model to assess the economic impact of floods, J. Econ. Behav. Organ., vol. 230, no. 106896, 2025, p. 106896. DOI: 10.1016/j.jebo.2025.106896
[8] Jun W. K., An M. H., Choi J. Y. Impact of the connected \& autonomous vehicle industry on the Korean national economy using input-output analysis, Technol. Forecast. Soc. Chang., vol. 178, no. 121572, 2022, p. 121572. DOI: 10.1016/j.techfore.2022.121572
[9] Zofio J. L., González J., Prieto A., Vicente J. Modelling the spatial and sectoral benefits of productivity enhancing innovations using a transport oriented multiregional {IO} framework: the `megatruck' in Spain, Econ. Syst. Res., vol. 35, no. 2, 2023, pp. 228-264. DOI: 10.1080/09535314.2021.1951178
[10] Auzina-Emsina A., Pocs R. "Impact of transport and storage sector on sustainable development: Evaluation using input-output model," in IMCIC 2019 - 10th International Multi-Conference on Complexity, Informatics and Cybernetics, Proceedings, 2019, pp. 1-6.
[11] Kim T.-J., Tromp N. The economic impact of the logistics industry in South Korea: Based on an input-output approach, LOGI - Sci. J. Transp. Logist., vol. 13, no. 1, 2022, pp. 174-185. DOI: 10.2478/logi-2022-0016
[12] Auzina-Emsina A., Ozolina V. High-technology industries competitiveness and regional allocation by nuts 3 regions in Latvia, 2017. DOI: 10.22616/rrd.23.2017.074
[13] Bormane S., Sloka B., Skiltere D. Sustainable consumption and waste management, Engineering for Rural Development, 2023. DOI: 10.22616/ERDev.2023.22.TF185
[14] Dolge K., Barisa A., Kirsanovs V., Blumberga D. The status quo of the {EU} transport sector: Cross-country indicator-based comparison and policy evaluation, Appl. Energy, vol. 334, no. 120700, 2023, p. 120700. DOI: 10.1016/j.apenergy.2023.120700
[15] Pakere I. et al. Ranking {EU} climate and energy policies, Environ. Clim. Technol., vol. 25, no. 1, 2021, pp. 367-381. DOI: 10.2478/rtuect-2021-0027
[16] Ozdemir S., Demirel N., Zaral\i F., Çelik T. Multi-criteria assessment framework for evaluation of Green Deal performance, Environ. Sci. Pollut. Res. Int., vol. 31, no. 3, 2024, pp. 4686-4704. DOI: 10.1007/s11356-023-31370-2
[17] Atstaja D. Renewable energy for Sustainable Development: Opportunities and current landscape, Energies, vol. 18, no. 1, 2025, p. 196. DOI: 10.3390/en18010196
[18] Auzina-Emsina A. Greener last-mile delivery technologies and regional development in Latvia: input-output approach, 23rd International Scientific Conference Engineering for Rural Development Proceedings, 2024. DOI: 10.22616/ERDev.2024.23.TF078
[19] Eurostat, "Eurostat Database," Symmetric input-output table at basic prices (product by product). [online] [15.03.2025] Available at: https://ec.europa.eu/eurostat/databrowser/view/naio_10_cp1700/default/table?lang=en&category=na10.naio_10.naio_10_n.naio_10_cp
[20] Heldt B., Matteis T., von Schmidt A., Heinrichs M. Cool but dirty food? - Estimating the impact of grocery home delivery on transport and {CO2} emissions including cooling, Res. Transp. Econ., vol. 87, no. 100763, 2021, p. 100763. DOI: 10.1016/j.retrec.2019.100763