CHEMICAL ENGINEERING TRANSACTIONS

VOL. 114, 2024

A publication of AIDIC

The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Min Zeng, Yee Van Fan, Xuechao Wang

ISBN 979-12-81206-12-0; **ISSN** 2283-9216

DOI: 10.3303/CET24114123

The Construction and Application of the Economy-Electricity-Emissions Input-Output (IO-E3) Table for Hungary

Krisztián Koppány

Széchenyi István University, Department of International and Applied Economics, Egyetem tér 1 Győr, Hungary
koppanyk@sze.hu

This paper presents the steps and methods of producing the IO-E3 Economy-Electricity-Emissions input-output table for Hungary, which contains 28 industries, 8 sub-industries of electric power plants, and 5 final demand categories. Simulations performed with the model show that the ongoing 120 % expansion of nuclear capacity can result in a 55.2 %, 35.1 %, and 30.1 % increase in electricity production, value-added, and greenhouse gas emissions if the structure of final demand and technology are not changed. Smart use of the predicted 17.48 TWh of electricity surplus, however, must precisely aim these changes to best serve Hungary's sustainability transition through harnessing technological developments and by changing economic structures.

1. Introduction

The examination of sustainable development issues requires an increasingly integrated approach: simultaneous thinking in several socio-economic and physical-ecological fields. Decision support models must link these subsystems. E3-type (Economy-Energy-Environment) input-output (IO) tables (like those of the World Input-Output Database, Dietzenbacher et al., 2013, Timmer et al., 2015) and models (like those of the Cambridge Econometrics, 2024) precisely serve this purpose. With their help, not only can the flow of products between productive and end-user sectors and the value-added (income) generation of industries be examined, but also the energy needs and environmental pollution of production and use, and even their indirect (multiplicative) effects on other sectors and the whole economy.

This study presents the steps and methods of producing an IO table (IOT) of this type using the Dissemination Database and STADAT tables of the Hungarian Central Statistical Office (HCSO, 2023), the statistics of the Hungarian Energy and Public Utility Regulatory Authority, financial reports of energy companies, the Electricity Maps web portal, and the information from interviewed industry experts, which will be reviewed in Section 2. Integrating and harmonizing the latest Hungarian official statistics and public financial data to construct an Economy-Electricity-Emissions IOT is a pioneering project. IO-E3 HUN 2020 table presents the examined subsystems in more detail than other currently available databases, albeit with a narrower interpretation of the acronym E3. It focuses on electricity in terms of energy production and use, and air pollution as one the most important environmental impacts. Applications in Section 3 show some input-output indicators calculated using IO-E3 to analyse the 2020 status of Hungary in an economy-electricity-emissions context. For illustration, Section 3 presents the result of a simulation investigating the economic, environmental, and energy supply consequences of a nuclear power plant capacity expansion. Section 4 concludes and sets possible directions for future research.

2. Data and methods

To compile the IO-E3 HUN table, the starting point was the official input-output table of Hungary by the Hungarian Central Statistical Office (HCSO, 2023), the latest available edition of which is for 2020. Other data and the supply and use tables available would have allowed an IOT for 2021 to be compiled (based on own calculations). However, both individual financial reports and sectoral aggregates reflected confusing post-COVID and war turbulences in energy markets in 2021-2022 (significant losses, negative output value of electricity trade, etc.). This confirmed the decision in favour of the reference year 2020.

Paper Received: 9 July 2024; Revised: 11 August 2024; Accepted: 8 December 2024
Please cite this article as: Koppány K., 2024, The Construction and Application of the Economy-Electricity-Emissions Input-Output (IO-E3) Table for Hungary, Chemical Engineering Transactions, 114, 733-738 DOI:10.3303/CET24114123

The air pollution database of the HCSO uses the same 65-sector breakdown as the official IO data. Although an environmentally augmented IOT is not available in Hungary, it was relatively easy to create it by combining the two databases. Serious challenges arose, however, during the production of the energy block, which required collecting and harmonising data from various sources, as well as applying expert estimates beyond official data. The most important task was the decomposition of the D35 Electricity, gas, steam and air conditioning supply (undivided both in official IOTs and air emission statistics) into D3511 Electricity production; D3512-14 Electricity transmission, distribution, and trade; D352 Gas supply; and D353 Steam (heat) and air conditioning supply, based on the production and sales data of industrial sectors by the Dissemination Database (technical identifier: ID403_W). The distribution ratios have been confirmed by the financial reports (bought from D&B Hungary) of companies from the D35 sector (approximately 1,500 organisations). Other input side categories of the four subsectors above, such as value-added and intermediate use by supplier industries, were also determined based on company reports.

The output of D351 Electricity production, estimated at 598,214 M HUF, was first broken down by user sectors on the basis of natural indicators (TJ, GWh) by the annual Eurostat-type energy balance of the Hungarian Energy and Public Utility Regulatory Authority (HEPURA) (MEKH, 2023), which presents a detailed report of primary production, exports, imports, change in stocks, transformation input and output, own use of the energy sector, distribution losses, and consumption of industries and households. Similarly to electricity, data on heat and natural gas production and consumption have also been processed and assigned to industries and sectors included in the IOT. The matching was obvious in most cases. However, some industries had to be merged according to the list presented in the first column of Table A1 in the Online appendix (Koppány, 2014).

To determine the output breakdown (i.e., sales to intermediate and final users) of the energy sector (i.e., row values of industries D3511, 3512-14, 352, and 353 in the IOT), natural rates of industrial, household, and export use were applied. Transmission and trading fees, i.e. revenues from different sectors in D3512-14 and 352, were initially assumed to be proportional to the consumption of the basic product, i.e. electricity and natural gas. Such a resolution assumes that everyone has access to electricity, heat, and related distribution services based on natural usage proportions and at the same prices; this, however, is not true. Companies from various sectors, households, and export partners obtain energy at different prices depending on the level of consumption and contractual terms. Sectoral export shares based on monetary values could be determined using ID403_W, but similar superior information is not available for industries and households. Therefore, excluding the export ratio, the remaining monetary row values were first allocated based on the proportions of usage measured in TJ. Then the formation of price differences was entrusted to a bi-proportional balancing algorithm, the RAS method widely used in IO analysis (Miller and Blair, 2009), that adjusted the cells of the initial block matrix to the D35 row values in the official IOT (as required column sums) and estimated output values of D3511, D3512-14, D352, and D353, respectively (as required row sums).

The next step was a further decomposition of the D3511 according to the primary energy sources: nuclear, gas and oil, coal, biomass, hydro, wind, solar, and other. The annual amount of electricity produced by different power plant subsectors is provided by the 6.1.1.9 STADAT table (HCSO, 2023) and the HEPURA (MEKH, 2023) energy balance. For the monetary values, financial report data have been exploited. The classification of power plants into the most characteristic subsector of electricity production was performed using the tables of HEPURA-licensed electricity producers. Approximately 89 % of the estimated output value of the electricity production sector could be classified this way. In Hungary, the nuclear power plant category includes a single company for which both output and value-added are clearly given. In the case of the other power plant disciplines, the previously defined ratios have been applied to the output value of total electricity production calculated without the nuclear power plant. Value-added ratios based on the financial data were employed for the output values of all D35 sub-branches (including D3511 by primary energy source, 3512-14, 352, and 353). These raw estimations were then adjusted to sum up to the total value added of D35 in the official IOT.

The HCSO does not provide data on air pollution, particularly caused by electricity production; only the emissions of the entire D35 sector are published. Direct greenhouse gas (GHG) emissions associated with different power plant sectors and primary energy sources have been estimated based on the available data on electricity and heat production from the HEPURA, the intensity and efficiency parameters of plants, and the specific g CO_2eq/kWh coefficients reported by the interactive Electricity Maps (2023) website.

Intermediate consumption of each power plant subsector, as well as electricity transmission, distribution and trade, gas, steam, and air conditioning supply, have been valued using direct input coefficients. A representative company was selected for each sector (in some cases, more than one), and their cost elements were assigned to the respective IO-E3 supplier industries. Input coefficients were determined as the ratios of inputs from each supplier industry and the company's output value. These proportions were then applied to the entire power plant sector. Row and column sums of intermediate use resulting from the product of the input coefficients and subsectors' output must be in line with the total sales and purchases either known from the official IOT or given by previous estimations. Naturally, these conditions were not met at first. A multi-step balancing procedure was applied: first horizontally, using various methods, and then with the RAS iteration again, starting with a column-wise adjustment.

The multi-month process of data collection and harmonisation, consultations with the related organisations (see Acknowledgements), and calculations resulted in an IOT with 28 industries (for the full list see Table A1 in the Online appendix (Koppány, 2024), 8 electric power plant subindustries, and 5 final demand categories, which was named IO-E3 HUN 2020 (Economy-Electricity-Emissions Input-Output Table of Hungary) and is shown (in an aggregated form) in Table A2 in the Online appendix (Koppány, 2024).

Fuel expenses related to personal vehicle (car) usage have been separated from other household consumption to prepare for future modelling exercises. In the case of e-vehicles, for the entire population, these expenses are still low in 2020 but are expected to increase significantly in the future. In the IO-E3 table, along with production and consumption data, the annual electricity generation capacity is also displayed in two separate rows with two different approaches. The first one can be referred to as theoretical electricity production potential, which represents the theoretical annual production under continuous operation and corresponds to the installed gross capacity. The second one is the practical electricity generation potential, which is the maximum annual production achievable, considering maintenance requirements, technical downtime, and local weather conditions (such as hours of sunshine and wind). The values found here were derived based on data and information available on the website of the Hungarian Electricity Industry Transmission System Operator (MAVIR, 2023), in addition to the HEPURA and HCSO statistics referred to above.

3. Applications and discussion of simulation results

Figure 1 shows the big picture of the economic, energy, and environmental structures of Hungary in 2020, which can be drawn using IO-E3 data directly. Two-thirds of the gross value added (GVA, a.k.a. GDP at basic prices) belongs to the Services (highest blue column). Hungarian economic policy, however, focuses on Manufacturing, which has a share of appr. 20 % in GVA and the highest (32.4 %) in electricity consumption (light orange). Electricity production (dark orange) does not cover domestic needs. Consequently, Hungary must import electricity in a significant amount, more than half of the domestic production. Together with a significant but much lower export level of excess electricity in peak-production periods, this results in a negative trade balance. After households, the energy sector has the second highest share of direct GHG emissions (grey). The share of manufacturing in total is not outstanding; however, there are significant deviations between different subsectors.

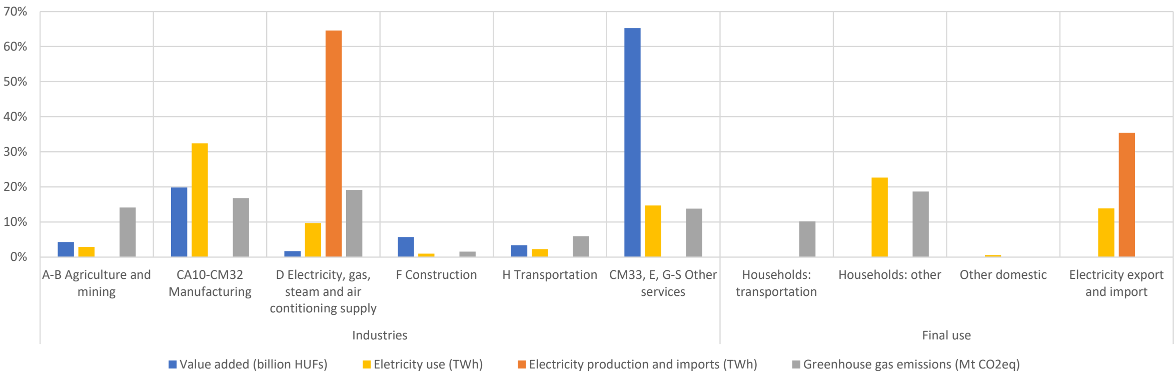


Figure 1: GVA, electricity and GHG emissions by productive industry and final use sector in Hungary, 2020 (No bars on the chart means that the category is not applicable or practically zero)

3.1 Input-output analyses of the economy-electricity-emissions status in 2020

With an input-output analysis of IO-E3 data, one can reveal more than direct shares. Figure A1 in the Online appendix (Koppány, 2024) compares direct and total (direct + indirect) value-added, electricity use, and emissions generated by the final demand for the products of indicated industry groups. Total backward linkages were calculated using the Leontief demand pull IO model and the product of final use of industries and GVA, electricity use, and GHG emission multipliers (Koppány, 2017) as well as see Table A1 in the Online appendix (Koppány, 2024). The results indicate that considering the whole domestic upstream value chain, manufacturing has a greater impact on Hungarian GVA, electricity use, and GHG emissions than its direct numbers show. (Despite the aggregated presentation, the calculations were performed with the detailed 28+8-industry IO-E3 table.)

Figure 2a highlights that exports, nearly 70 % of which are made up of manufacturing, with their total linkages, give 38 % of Hungarian value added (left bar, red part), comprise half the total electricity use (middle bar, red part), and are responsible for 35 % of GHG emissions. Households generate half the total emissions (right bar, green part). Figure 2b shows Hungarian industries from an E3-dimensional aspect, where the size of the bubbles indicates the total GVA belonging to the entire upstream value chains of industries, and horizontal and vertical coordinates measure the GHG and electricity content of one (or thousand) HUF(s) of GVA. The manufacturing of motor vehicles (CL29) and electronic products (CI26), being the focus of industrial policy, might have the lowest GVA multipliers, and yet, due to huge amounts of exports, their value-added impacts are still significant. The specific electricity and GHG content of the GVA they induce is also among the lowest. Table A1 in the Online appendix (Koppány, 2024) presents all the indicators that have been used for the IO calculations.

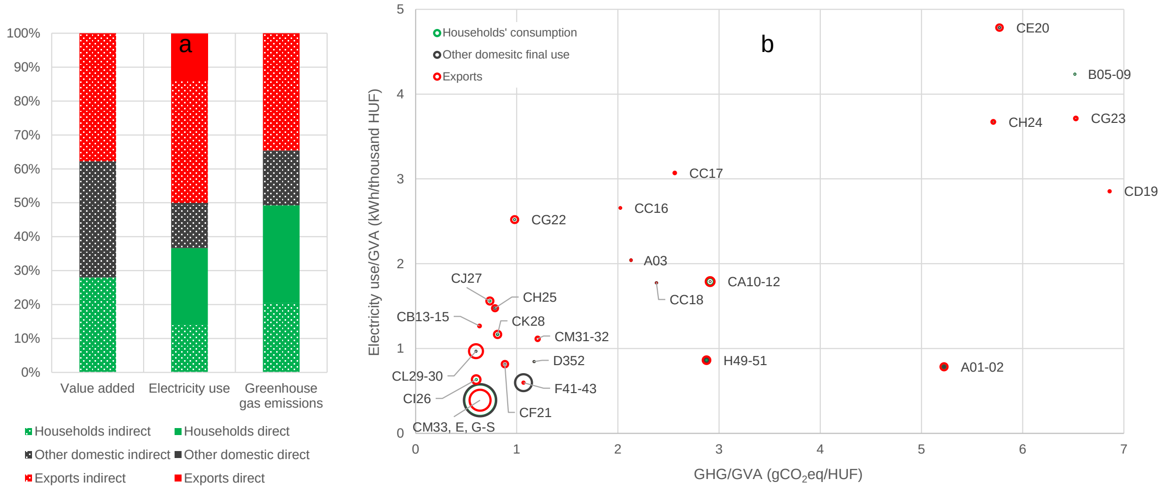


Figure 2: Share of final users in value-added, electricity use, and GHG emissions in Hungary, 2020 (a); Hungary's industries from an E3-dimensional (economy, energy, emissions) aspect, 2020 (b)

3.2 Electricity production: mix and carbon intensity

Electricity production, with its 10.9 Mt of direct GHG (see Figure 3a), has a 14.2 % share in total emissions; and in the 35 TWh of total annual electricity produced by the sector, the nuclear power plant of Paks1, with its 16 TWh output, makes the highest (46 %) contribution (see Figure 3b). Figure 3b also shows that its carbon intensity is minimal (5 gCO_2eq/kWh); 90 % of emissions from electricity production are caused by gas and coal power plants. Table 1 presents the carbon intensities of different power plants in detail. The literature generally reports direct production intensities (UNECE, 2022; Ritchie et al., 2024); however, carbon statistics for ready-to-use (socket) electricity must contain transmission, distribution and trading services, and involve losses of transmission and distribution, own use of power plants, and several indirect activities in the upstream supply chains of suppliers, as well, which in turn cause additional emissions. IO analysis detects that in Hungary, all these effects triple the carbon intensity of nuclear electricity.

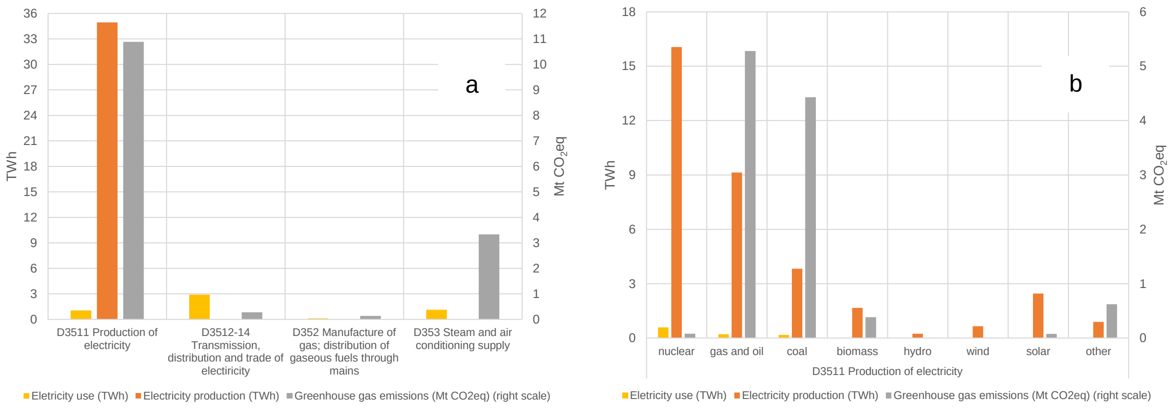


Figure 3: Electricity use, production, and GHG emissions in the whole D35 energy sector (a) and in the D3511 Electricity production industry (b) in Hungary, 2020

Table 1: Direct, indirect, and total carbon intensity of electricity (gCO$_2$eq/kWh) in Hungary 2020

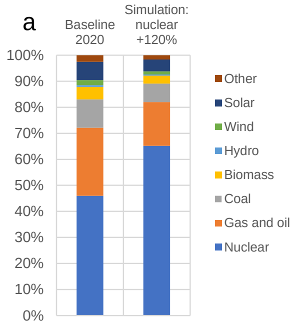
		Nuclear	Gas and oil	Coal	Biomass	Hydro	Wind	Solar	Other	D3511
Direct	Production	5	578	1,158	230	11	13	31	700	312
	Transmission, distribution, and trade	5	5	5	5	5	5	5	5	5
	Ready-to-use (socket) electricity	10	583	1,163	235	16	18	36	705	317
Indirect	Production	2	13	26	50	4	4	1	42	11
	Transmission, distribution, and trade	3	10	19	9	3	3	6	99	9
Total	Production	7	591	1,184	280	15	17	32	742	323
	Transmission, distribution, and trade	8	15	24	14	8	8	12	104	14
	Ready-to-use (socket) electricity	15	606	1,208	294	24	26	44	846	337

3.3 Simulation of a nuclear capacity increase

Despite the higher total carbon intensity, the ongoing project aspiring to a 120 % increase in Hungary's nuclear production capacities (Paks2) can also be justified from an economic, energy and environmental policy point of view. Nuclear electricity is still the cleanest and cheapest option. Paks1 and Paks2 together can increase the share of nuclear power in the electricity mix to over 65 % (see Figure 4a) and decrease the overall direct carbon intensity of Hungarian-produced socket electricity from 317 to 208 gCO$_2$eq/kWh. Developing and extending the production of preferred manufacturing branches, electrification of transportation, heating, and many other fields, together with expected technology changes of the net zero transition, all mean a huge electricity demand increase in the future. Simulations performed using IO-E3 data predict a 55.2 % increase in electricity production (see Figure 4b). For this extra electricity to be ready to use, a 36 % growth in the output of industry D3512-14 Electricity transmission, distribution and trade is needed. Maintaining the current level of exports and imports, direct own use of plants and network losses alone cause a 3.2 % increase in electricity use. Once the indirect effects are included, this rises to 3.3 %, leaving a total of 17.48 TWh of electricity for other purposes.

Obviously, 17.48 TWh of electricity surplus cannot replace 19.18 TWh of imports. It is also advisable to maintain imports and exports because they can balance domestic production and consumption, and it is still conceivable that in certain periods, Hungary can get cheaper and cleaner electricity from imports than production.

A 0.7 % and 0.4 % increase in GVA and GHG emissions occur even if Hungary does nothing with its 17.48 TWh of extra electricity and simply exports it. Simulation#2 investigates a hypothetical business-as-usual scenario when only the size of the total final use increases, and its structure remains unchanged at the 2020 levels. In this case, assuming no other constraints, domestic use of total electricity surplus can result in a 35.1 % GVA and 30.1 % GHG emission growth (see Figure 4b). The GHG content of one unit of GVA decreases by 3.7 %, from 577 to 556 g/USD, which is not significant and is still above the global average (Román et al., 2019). This scenario encounters several input constraints (e.g. the required increase in employment and other energy use) that are impossible to resolve. In any case, an unchanged economic structure and technology are rather unlikely assumptions. Accordingly, the use of expected electricity surplus energy must be defined in a way that best serves Hungary's sustainability transition by harnessing technological developments and changing the economic structures. Further simulations using the IO-E3 model can help to assess the alternatives.



b

		Baseline 2020	Simulation#1: nuclear +120%		Sim#2: nuclear +120%; max growth by energy surplus with fixed final use structure and technology
			Direct effects	Direct and indirect effects	
Electricity production (TWh)		34.9	54.2	54.2	54.2
% change to the baseline			55.2%	55.2%	55.2%
Electricity use (TWh)		54.1	55.8	55.9	73.4
% change to the baseline			3.2%	3.3%	35.6%
Electricity surplus (TWh)			17.52	17.48	0
GVA (billion HUF)		40,861	41,083	41,159	55,187
% change to the baseline			0.5%	0.7%	35.1%
GHG emissions (Mt CO2eq)		76.6	76.8	76.9	99.6
% change to the baseline			0.3%	0.4%	30.1%
GHG content of value added (GHG / GVA, gCO2eq/ HUF)	1 HUF	1.875	1.869	1.868	1.805
	1 USD	577	576	575	556
% change to the baseline			-0.3%	-0.4%	-3.7%

Figure 4: Impact analysis of a nuclear capacity expansion in Hungary: the change in the electricity mix (a); and simulation results (b)

4. Conclusions and further research

Input-output tables serve as a primary database for multisectoral macro models describing the direct and indirect linkages between industries, final users, output, and value-added. Extended by special blocks, they can be used for more extensive and integrated analyses involving not only economic but also energy production and use and environmental issues. This paper presented such a database, the IO-E3 Economy-Electricity-Emissions IOT for Hungary, which contains the examined subsystems in more detail than any other currently available database. With its special focus, it allows for previously impossible model calculations to be performed related to the changes in the electricity mix. The export-oriented, high-volume-manufacturing-focused industrial policy of Hungary, together with efforts to decrease GHG emissions, requires cleaner and cheaper electricity. Simulations performed using IO-E3 showed that a 120 % nuclear capacity expansion could result in a 55.2 %, 35.1 %, and 30.1 % increase in electricity production, GVA, and GHG emissions, assuming no change in the structure of final demand and technology. Smart use of the predicted 17.48 TWh of electricity surplus, however, must precisely aim these changes to best serve Hungary's sustainability goals. Integrated E3 assessment and impact analyses of other planned modifications in the energy mix (e.g. new gas turbine power plants, greening heat supply) and alternatives for industrial and household use of the excess electricity (e.g. green hydrogen, e-mobility) are subjects for further research which hopefully support decisions of policymakers.

Acknowledgments

This research was supported by the HUMDA Hungarian Motorsport and Green Mobility Development Agency. The author thanks László Winkler (HEPURA), Zoltán Mayer (HFC Hungary), Tamás Bándy (Messer Hungaroház Kft.), Barna Hanula and Géza Köteles (Széchenyi István University) for the consultations, and Natasha Bailey-Borbély (Széchenyi István University) for the proofreading.

References

Cambridge Econometrics, 2024, <https://www.camecon.com/how/>, accessed 01.04.2024.

Dietzenbacher E., Los B., Stehrer, R., Timmer, M., De Vries, G., 2013, The Construction of World Input–Output Tables in the WIOD Project. Economic Systems Research, 25(1), 71-98, DOI: 10.1080/09535314.2012.761180.

Electricity Maps, 2023, <https://appelectricitymapscom/zone/HU>, accessed 01.09.2023.

HCSO, 2023, Hungarian Central Statistical Office. Dissemination Database and STADAT tables. <https://statinfo.ksh.hu/Statinfo/themeSelector.jsp?&lang=en>, <https://www.ksh.hu/?lang=en>, accessed 01.09.2023.

Koppány K, 2024, Online appendix to the paper “The Construction and Application of the Economy-Electricity-Emissions Input-Output (IO-E3) Table for Hungary” <https://drive.google.com/file/d/1uNwqZYmT0r940qvifM2AybprEdfEIZqq/view?usp=drive_link>, accessed 20.10.2024.

Koppány K., 2017, Macroeconomic and Regional Impact Analysis with Multiplier Models in MS Excel: Hungarian Applications and Numerical Examples, Széchenyi István University, Győr, Hungary, ISBN 978-963-06-4385-6, 255.

MAVIR, 2024, Data publication. <https://mavir.hu/web/mavir-en/data-publication>, accessed 01.04.2024.

MEKH, 2023, Table 7.4 Annual Eurostat-type energy balance. <https://mekh.hu/annual-data>, accessed 01.09.2023.

Miller R.E., Blair P.D., 2009, Input-Output Analysis. Foundations and Extensions, Second Edition, Cambridge University Press, Cambridge, 2009. DOI: 10.1017/cbo9780511626982.003

Ritchie H., Rosado P., Roser M., 2024. Energy Production and Consumption. Our World in Data. <https://ourworldindata.org/energy-production-consumption>, accessed 08.04.2024.

Román M.V., Corsatea T.D., Amores A.F., Neuwahl F., Velázquez Afonso A., Rueda-Cantuche J.M., Arto I., Lindner S., 2019, World input-output database environmental accounts, Update 2000-2016. Joint Research Centre (European Commission), ISSN 1831-9424, ISBN 978-92-76-02068-4, DOI: 10.2760/024036.

Timmer M.P., Dietzenbacher E., Los B., Stehrer R., de Vries G.J., 2015, An Illustrated User Guide to the World Input–Output Database: The Case of Global Automotive Production. Review of International Economics 23(3), 575–605, DOI: 10.1111/roie.12178.

UNECE, 2022, Carbon Neutrality in the UNECE Region: Technology Interplay under the Carbon Neutrality Concept. <https://unece.org/sustainable-energy/publications/carbon-neutrality-unece-region-technology-interplay-under-carbon>, accessed 01.09.2023.