Recycling and Biomass Influence on the Production-Based CO2 Intensity Based on Circular Economy Concept

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Abstract
In a closed loop structure, the circular economy reflects a concept for converting material and energy wastes into capital for other purposes. The circular economy's key goal is to reduce energy and material waste. The best-case scenario will be to eliminate wastes and repurpose them, which is one of the key goals of the circular economy. The circular economy and sustainable development are inextricably linked. The framework reflects resource reuse and recycling in order to reduce waste and the use of biodegradable items that can be returned to the ecosystem after rejection. Many programs are being developed to incorporate the circular economy in order to apply the system's best practices. Recycling and reusing goods for the same or new items are the best practices for reducing waste and energy consumption. The main goal of the study was to analyze the effect of waste generation and recycling on production-based CO2 intensity based on circular economy concept. For such a purpose adaptive neuro fuzzy inference system (ANFIS) was implemented since the methodology is suitable for statistical investigation of strongly nonlinear data sample due to features of fuzzy logic system. Generated and recycled waste including biomass is the most influential factors for the production-based CO2 intensity based on circular economy concept. The obtained results could represent the best practices for implementation of circular economy concept.

Keywords: circular economy; waste; recycling; biomass; ANFIS.

1. Introduction

The circular economy is a framework for long-term sustainability that aims to reduce material and energy waste. Materials cycles are the central principle of the circular economy, which aims to minimize negative environmental effects, reduce energy consumption, and promote economic growth. The linear economy model has dominated industrial growth, resulting in pollution and the overuse of scarce natural resources. Reusing, remanufacturing, restoring, and updating goods or materials are all part of the circular economy. The circular economy in the energy sector is focused on renewable energy sources such as solar, wind, biomass, and waste-derived energy. One of the most critical circular economy principles is the use of biodegradable materials that can be returned to the atmosphere after being rejected, resulting in no waste.
In article [1] has been verified that the artificial neural network can be applied in different computational tasks in selected circular economy problems. Recycling and utilization of biomass constituents have been verified as the main factors in implementation of circular economy concept [2]. Circular economy presents a new way of economic growth based on effective usage of energy and material resources and environmental protection [3]. Results in article [4] have been shown that in circular economy domain was made important contributions to research but these contributions are heterogeneous with important differences and academic research does not fully align with the policy agenda. Hence there is need for more comprehensive investigation of circular economy parameters. It has been shown that the sustainable development in Industry 4.0 context could contribute to circular economy [5, 6]. Results in article [7] have been shows that there are large distinctions between different regions in China in circular economy development. Hence each region and each country have different factors and influences in circular economy development. Circular economy is based on different variables and factors and experts from different fields could make decisions based on the multiple attributed. This is not easy task and hence there is need to develop a decision-making model based on the multivariable group, which could facilitate decision and coordination between the different experts [8]. Results in article [9] have been indicated that the circular economy could improve economic development and ecological restoration as well. In article [10] has been shown important policy implications in periodical shift from the traditional linear economy to a circular economy. The impact of circular economy on economic growth has been investigated in article [11] and results have been shown that the GDP growth rate decreases significantly but the economic decline gradually recovers as time goes on. Results in article [12] have been shown a positive correlation between resources and environmental performance with the driving factors for circular transformation being mainly GDP and leading industries.

There are many initiatives in the works to incorporate circular economy best practices into the scheme. Recycling and reusing goods for the same or different items are the best practices. The main goal of the study was to analyze the effect of effect of waste generation and recycling on production-based CO2 intensity based on circular economy concept. For such a purpose adaptive neuro fuzzy inference system (ANFIS) [13] was implemented since the methodology is suitable for statistical investigation of strongly nonlinear data sample due to features of fuzzy logic system.

2. Methodology

2.1. Circular economy concept
The circular economy is an economic mechanism whose primary goal is to eradicate waste and make continuous use of resources. In order to build a closed loop structure, the key tasks in the circular economy are to reuse, restore, remanufacture, and recycle. The circular economy's key aim is to reduce resource inputs and waste, as well as pollution and carbon emissions. The circular economy's second aim is to keep goods, facilities, and infrastructure in use for longer periods of time. The circular economy principle is illustrated in Figure 1. Other processes should use maternal and oil wastes as inputs. As a result, in order to generate regenerative resources and remove waste materials and energy, a regenerative approach is needed. The circular economy has five key measures that result in a closed loop structure. (Figure 2).
Figure 1: Circular economy concept
2.2. Scottish Household waste

The used dataset was generated between 2017 and 2019 as summary of household waste data generated in Scotland and managed by or on behalf of Scottish local authorities. The carbon impact is a measure of the whole-life carbon impacts of waste, from resource extraction and manufacturing emissions, right through to waste management emissions. The carbon impact of household waste generated and managed as tonnes of carbon dioxide equivalent (TCO2e). All of the data in this report is available in the Household Waste Discover Data tool on Scotland's Environment website (https://www.environment.gov.scot/). Annual household waste summary data tables are also available to download in Excel format on SEPA's web site (https://www.sepa.org.uk/environment/waste/waste-data/waste-data-reporting/household-waste-data/). Tables 1 shows the used dataset with 4 inputs and one output. The first input represents the total generated waste in in tonnes per person. The second input is recycled waste in tonnes per person. Waste recycled includes waste reused, recycled or composted. The third input represents wastes of other division from landfill in tonnes per person. Other diversion from landfill is waste material not recycled or landfilled. This includes net waste incinerated, incinerator outputs recycled, and organic material recycled that does not meet quality standards. The fourth input represent the waste landfilled. The output represents the Carbon impacts of Scottish household waste in TCO2e. Data was submitted by all 32 Scottish local authorities using the web-based reporting tool WasteDataFlow.
Table 1: Scottish Household waste generated and managed per person between 2017-2019

| Local Authority          | Year | Generated (tonnes per person) | Recycled (tonnes per person) | Other diversion from landfill (tonnes per person) | Landfilled (tonnes per person) | Carbon Impact (TCO2e per person) |
|--------------------------|------|--------------------------------|------------------------------|-----------------------------------------------|-------------------------------|----------------------------------|
| Aberdeen City            | 2017 | 0.38                           | 0.17                         | 0.08                                          | 0.14                          | 0.87                             |
| Aberdeenshire            | 2017 | 0.49                           | 0.21                         | 0.01                                          | 0.27                          | 1.24                             |
| Angus                    | 2017 | 0.48                           | 0.27                         | 0.10                                          | 0.11                          | 1.00                             |
| Argyll and Bute          | 2017 | 0.58                           | 0.23                         | 0.08                                          | 0.27                          | 1.46                             |
| City of Edinburgh        | 2017 | 0.39                           | 0.16                         | 0.01                                          | 0.22                          | 0.99                             |
| Clackmannanshire         | 2017 | 0.53                           | 0.31                         | 0.06                                          | 0.16                          | 1.08                             |
| Dumfries and Galloway    | 2017 | 0.51                           | 0.14                         | 0.16                                          | 0.21                          | 1.47                             |
| Dundee City              | 2017 | 0.43                           | 0.15                         | 0.25                                          | 0.03                          | 1.04                             |
| East Ayrshire            | 2017 | 0.46                           | 0.24                         | 0.04                                          | 0.17                          | 0.98                             |
| East Dunbartonshire      | 2017 | 0.52                           | 0.25                         | 0.06                                          | 0.21                          | 1.21                             |
| East Lothian             | 2017 | 0.48                           | 0.26                         | 0.00                                          | 0.22                          | 1.07                             |
| East Renfrewshire        | 2017 | 0.50                           | 0.34                         | 0.02                                          | 0.15                          | 1.01                             |
| Falkirk                  | 2017 | 0.47                           | 0.26                         | 0.05                                          | 0.15                          | 0.94                             |
| Fife                     | 2017 | 0.48                           | 0.26                         | 0.03                                          | 0.19                          | 0.94                             |
| Glasgow City             | 2017 | 0.36                           | 0.10                         | 0.02                                          | 0.24                          | 1.10                             |
| Highland                 | 2017 | 0.55                           | 0.24                         | 0.01                                          | 0.31                          | 1.37                             |
| Inverclyde               | 2017 | 0.35                           | 0.20                         | 0.02                                          | 0.13                          | 0.72                             |
| Midlothian               | 2017 | 0.47                           | 0.24                         | 0.02                                          | 0.21                          | 1.09                             |
| Moray                    | 2017 | 0.53                           | 0.31                         | 0.00                                          | 0.23                          | 1.02                             |
| Na h-Eileanan Siar       | 2017 | 0.54                           | 0.13                         | 0.06                                          | 0.35                          | 1.43                             |
| North Ayrshire           | 2017 | 0.46                           | 0.26                         | 0.01                                          | 0.19                          | 1.01                             |
| North Lanarkshire        | 2017 | 0.46                           | 0.18                         | 0.02                                          | 0.26                          | 1.20                             |
| Orkney Islands           | 2017 | 0.49                           | 0.09                         | 0.22                                          | 0.15                          | 1.32                             |
| Perth and Kinross        | 2017 | 0.49                           | 0.28                         | 0.03                                          | 0.19                          | 0.93                             |
| Renfrewshire             | 2017 | 0.47                           | 0.23                         | 0.11                                          | 0.13                          | 1.11                             |
| Scottish Borders         | 2017 | 0.46                           | 0.19                         | 0.01                                          | 0.27                          | 1.17                             |
| Shetland Islands         | 2017 | 0.42                           | 0.03                         | 0.29                                          | 0.09                          | 1.39                             |
| South Ayrshire           | 2017 | 0.50                           | 0.28                         | 0.05                                          | 0.18                          | 1.12                             |
| South Lanarkshire        | 2017 | 0.48                           | 0.23                         | 0.00                                          | 0.25                          | 1.17                             |
| Stirling                 | 2017 | 0.43                           | 0.24                         | 0.07                                          | 0.13                          | 0.90                             |
| West Dunbartonshire      | 2017 | 0.49                           | 0.23                         | 0.04                                          | 0.21                          | 1.17                             |
| West Lothian             | 2017 | 0.39                           | 0.24                         | 0.04                                          | 0.11                          | 0.80                             |
| Aberdeen City            | 2018 | 0.38                           | 0.18                         | 0.12                                          | 0.08                          | 0.87                             |
| Aberdeenshire            | 2018 | 0.46                           | 0.20                         | 0.01                                          | 0.25                          | 1.18                             |
| Angus                    | 2018 | 0.47                           | 0.26                         | 0.19                                          | 0.02                          | 0.97                             |
| Argyll and Bute          | 2018 | 0.56                           | 0.21                         | 0.09                                          | 0.26                          | 1.38                             |
| City of Edinburgh        | 2018 | 0.37                           | 0.14                         | 0.03                                          | 0.19                          | 0.95                             |
| Clackmannanshire         | 2018 | 0.51                           | 0.29                         | 0.01                                          | 0.21                          | 1.04                             |
| Dumfries and Galloway    | 2018 | 0.53                           | 0.15                         | 0.15                                          | 0.24                          | 1.53                             |
| Dundee City              | 2018 | 0.41                           | 0.15                         | 0.23                                          | 0.03                          | 1.00                             |
| East Ayrshire            | 2018 | 0.44                           | 0.23                         | 0.04                                          | 0.17                          | 0.97                             |
| East Dunbartonshire      | 2018 | 0.48                           | 0.26                         | 0.09                                          | 0.12                          | 1.03                             |
| East Lothian             | 2018 | 0.47                           | 0.25                         | 0.02                                          | 0.20                          | 1.05                             |
| East Renfrewshire        | 2018 | 0.46                           | 0.31                         | 0.01                                          | 0.14                          | 0.94                             |
| Falkirk                  | 2018 | 0.43                           | 0.22                         | 0.02                                          | 0.19                          | 0.97                             |
| Fife                     | 2018 | 0.45                           | 0.23                         | 0.03                                          | 0.19                          | 0.91                             |
| Glasgow City             | 2018 | 0.39                           | 0.10                         | 0.03                                          | 0.27                          | 1.17                             |
| Highland                 | 2018 | 0.54                           | 0.23                         | 0.03                                          | 0.28                          | 1.35                             |
| Inverclyde               | 2018 | 0.36                           | 0.20                         | 0.02                                          | 0.14                          | 0.74                             |
| Midlothian               | 2018 | 0.46                           | 0.27                         | 0.06                                          | 0.13                          | 1.01                             |
| Moray                    | 2018 | 0.50                           | 0.29                         | 0.00                                          | 0.21                          | 0.96                             |
| Na h-Eileanan Siar       | 2018 | 0.53                           | 0.12                         | 0.07                                          | 0.35                          | 1.41                             |
| North Ayrshire           | 2018 | 0.45                           | 0.25                         | 0.05                                          | 0.16                          | 1.04                             |
| North Lanarkshire        | 2018 | 0.43                           | 0.19                         | 0.06                                          | 0.18                          | 1.04                             |
| Orkney Islands           | 2018 | 0.46                           | 0.10                         | 0.22                                          | 0.12                          | 1.22                             |
| Perth and Kinross        | 2018 | 0.47                           | 0.25                         | 0.03                                          | 0.20                          | 0.93                             |
| Renfrewshire             | 2018 | 0.46                           | 0.22                         | 0.14                                          | 0.10                          | 1.07                             |
| Scottish Borders         | 2018 | 0.46                           | 0.18                         | 0.01                                          | 0.27                          | 1.16                             |
|                | 2018  | 2018  | 2018  | 2018  | 2018  |
|----------------|-------|-------|-------|-------|-------|
| Shetland Islands| 0.42  | 0.04  | 0.28  | 0.09  | 1.35  |
| South Ayrshire  | 0.50  | 0.26  | 0.06  | 0.18  | 1.11  |
| South Lanarkshire| 0.44  | 0.24  | 0.00  | 0.20  | 0.93  |
| Stirling        | 0.47  | 0.20  | 0.05  | 0.22  | 1.15  |
| West Dunbartonshire| 0.41  | 0.27  | 0.04  | 0.10  | 0.83  |
| West Lothian    | 0.37  | 0.18  | 0.12  | 0.07  | 0.79  |
| South Lanarkshire| 0.47  | 0.21  | 0.01  | 0.25  | 1.19  |
| Shetland Islands| 0.42  | 0.07  | 0.27  | 0.08  | 1.28  |
| South Ayrshire  | 0.47  | 0.27  | 0.05  | 0.15  | 0.97  |
| South Lanarkshire| 0.44  | 0.24  | 0.00  | 0.20  | 0.92  |
| Stirling        | 0.45  | 0.25  | 0.00  | 0.20  | 0.92  |
| West Dunbartonshire| 0.45  | 0.20  | 0.05  | 0.20  | 1.07  |
| West Lothian    | 0.42  | 0.25  | 0.11  | 0.06  | 0.87  |

Carbon Impact is a measure of the whole-life carbon impacts of waste, from resource extraction and manufacturing emissions, right through to waste management emissions, regardless of where in the world these impacts occur. The carbon impact of waste was developed by Zero Waste Scotland (https://www.zerowastescotland.org.uk/content/whatcarbon-metric).

Household waste includes:
- household waste treated by incineration, including any incinerator bottom ash and metals from bottom ash that are diverted from landfill,
- weight loss that occurs during the composting/digestion of waste to PAS 100/110 and non-PAS 100/110 compost/digestate where the output is landfilled,
- Compost like output (CLO) that is not landfilled,
- weight loss that occurs during mechanical and biological treatment processes,

Recycling rate is waste recycled as a percentage of all waste generated. Note that total waste generated does not equal total waste managed due to stockpiled waste, which is counted in the generation figures and will be included in the managed figures in the year it is sent to final management.
TCO2e is tonnes of carbon dioxide equivalent, which is a measure that allows the comparison of greenhouse gases relative to one unit of CO2. Waste composted is waste recycled by biological treatment through composting at a composting plant or through digestion at an anaerobic digestion facility. Waste generated is waste collected by or on behalf of local authorities that is managed within the relevant reporting year. This might include treated waste stockpiled prior to final management.

Waste landfilled includes all household waste that is disposed of at a landfill site instead of being recycled or diverted from landfill through other methods. It also includes incinerator ash that is landfilled, plus any recycling and composting rejects that occur during collection, sorting or further treatment that go to landfill.

Waste managed includes all wastes recycled, diverted from landfill and landfilled within the relevant reporting year. This includes stockpiled waste from a previous year sent to final management but excludes treated waste stockpiled prior to final management.

Waste recycled includes recyclable materials that have been recycled or reused and also biodegradable materials that have been composted or digested. The amount of waste recycled, reused and composted is that accepted by the reprocessor facility. As such it excludes any recycling rejects that occur during collection, sorting or further treatment.

### 2.3. OECD Green Growth database for CO2 intensity

In this study was used energy and non-energy material productivity parameters for CO2 intensity evaluation. Non-energy material productivity parameters are based on the waste materials and recycling. Energy productivity parameters represent energy consumption. In this study are used OECD Green Growth database [14] which contains selected indicators for monitoring progress towards green growth to support policy making and inform the public at large. The database synthesizes data and indicators across a wide range of domains. The database covers OECD members.

The indicators have been selected according to well-specified criteria and embedded in a conceptual framework. The main goal is to capture the main features of green growth based on environmental and resource productivity. There is need to indicate whether economic growth is becoming greener with more efficient use of natural capital and to capture aspects of production which are rarely quantified in economic models and accounting frameworks. Two sets of data are created. The first set represent energy productivity parameters (Table 2). The second set represent non-energy productivity parameters (Table 3).

#### Table 2: OECD Energy productivity parameters [14]

| Energy productivity, GDP per unit of TRES | Energy intensity, TRES per capita | Total primary energy supply, Index 2000=100 | Total primary energy supply | Renewable energy supply, % total energy supply | Renewable electricity, % total electricity generation | Energy consumption in agriculture, % total energy consumption | Energy consumption in services, % total energy consumption | Energy consumption in industry, % total energy consumption | Energy consumption in transport, % total energy consumption | Energy consumption in other sectors, % total energy consumption | Production-based CO2 intensity, energy-related CO2 per capita, Tonnes |
|-----------------------------------------|---------------------------------|---------------------------------|----------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 8826.367                                | 3.254377                        | 95.4406                         | 1679.353      | 6.420661                        | 18.517                          | 2.560462                        | 12.23068                        | 26.22146                        | 24.68238                        | 35.91433                        | 7.46                            |
| 11731.95                                | 3.158865                        | 100.780                         | 1775.66        | 12.73953                        | 24.7079                         | 2.440972                        | 12.62419                        | 27.86390                        | 26.97872                        | 34.71564                        | 6.62                            |
It reflects, at least partly, efforts to improve energy efficiency and to reduce carbon and other atmospheric emissions. Together with energy intensity, these indicators also reflect structural and international aviation bunkers ± stock changes. Energy intensity is calculated as TPES per capita, expressed as an index with values in 2000 normalized to equal 100. Renewable energy supply is calculated as a share of renewable sources in TPES (expressed as percentage). Renewables include biomass, municipal waste, and industrial waste, in addition to hydro, geothermal, solar, and wind. Non-energy material productivity is calculated as GDP per unit of Total Primary Energy Supply (TPES).

**Table 3: OECD Non-energy material productivity parameters [14]**

| Non-energy material productivity, GDP per unit of DMC | Biomass, % of DMC | Non-metallic minerals, % of DMC | Metals, % of DMC | Municipal waste generated, kg per capita | Production-based CO2 intensity, energy-related CO2, % of GDP |
|-----------------------------------------------------|------------------|---------------------------------|----------------|----------------------------------------|-----------------------------------------------|
| 0                                                   | 33.33333         | 33.33333                        | 33.33333       | 477.872                                 | 7.46                                           |
| 3.40258                                              | 31.15053         | 63.48703                        | 5.114901       | 439.218                                 | 6.65                                           |
| 3.76549                                              | 33.57956         | 60.98759                        | 6.583452       | 487.942                                 | 5.66                                           |
| 3.67792                                              | 32.05299         | 59.19372                        | 6.780865       | 481.19                                  | 6.39                                           |
| 3.81599                                              | 35.26301         | 58.32494                        | 6.41154        | 490.822                                 | 6.06                                           |
| 3.98615                                              | 33.89724         | 58.94004                        | 7.178273       | 482.439                                 | 6.13                                           |
| 4.04387                                              | 34.35774         | 58.54791                        | 6.934349       | 494.537                                 | 6.11                                           |
| 3.92684                                              | 34.29899         | 59.33814                        | 6.626866       | 493.16                                  | 6.16                                           |
| 1.78646                                              | 30.16415         | 39.51822                        | 39.6885        | 369.885                                 | 8.32                                           |
| 3.08073                                              | 21.9867         | 57.24782                        | 20.7681        | 616.023                                 | 9.81                                           |
| 2.06352                                              | 22.77053         | 57.10828                        | 20.6297        | 640.808                                 | 9.81                                           |
| 2.21739                                              | 22.86433         | 59.90213                        | 17.34328       | 645.143                                 | 10.09                                          |
| 2.87442                                              | 28.32773         | 55.72836                        | 20.94915       | 630.523                                 | 10.21                                          |
| 2.53041                                              | 28.3162         | 55.46878                        | 21.3612        | 671.748                                 | 10.53                                          |
| 2.32815                                              | 29.64258         | 55.23095                        | 21.5433        | 616.236                                 | 10.72                                          |
| 3.111501                                             | 30.84143         | 44.54292                        | 24.61556       | 617.478                                 | 10.65                                          |
| 4.232011                                             | 31.58254         | 43.19353                        | 25.25762       | 619.287                                 | 10.31                                          |
| 3.37943                                              | 32.44012         | 41.88441                        | 25.67547       | 622.326                                 | 10.34                                          |
| 3.48905                                              | 33.20529         | 40.65403                        | 26.1419        | 617.613                                 | 10.24                                          |
| 3.62182                                              | 33.97746         | 40.41026                        | 26.61228       | 614.56                                  | 10.20                                          |
| 3.27567                                              | 19.43443         | 62.07805                        | 18.49272       | 423.211                                 | 13.52                                          |
| 2.465624                                             | 20.57624         | 62.14111                        | 17.43689       | 486.842                                 | 13.50                                          |
| 6.62294                                              | 20.64682         | 59.03111                        | 20.32029       | 494.778                                 | 14.36                                          |
| 3.102619                                             | 21.48284         | 57.75633                        | 20.76732       | 434.163                                 | 13.74                                          |
| 3.675303                                             | 22.1197         | 55.03288                        | 22.84772       | 394.826                                 | 12.41                                          |
| 3.68839                                              | 22.45235         | 54.13111                        | 23.26355       | 393.49                                  | 11.94                                          |
| 3.77810                                              | 22.74282         | 49.18265                        | 25.58282       | 390.377                                 | 11.40                                          |
| 3.89764                                              | 23.20368         | 48.57331                        | 26.29542       | 390.61                                  | 11.58                                          |
| 4.23670                                              | 25.54854         | 47.99194                        | 26.94564       | 392.302                                 | 10.67                                          |
| 4.52671                                              | 47.07981         | 47.02766                        | 26.95535       | 393.837                                 | 11.16                                          |
| 4.697372                                             | 26.40974         | 45.95644                        | 57.84644       | 393.326                                 | 10.91                                          |
| 4.85577                                              | 26.6905          | 45.1672                         | 27.8841        | 390.666                                 | 10.68                                          |
waste). Renewable electricity is calculated as a share of renewables in electricity production (%).

Energy consumption in agriculture is expressed as a share of total energy consumption (%). Energy consumption in agriculture includes deliveries to users classified as agriculture, hunting and forestry by the International Standard Industrial Classification (ISIC). Therefore, it includes energy consumed by such users whether for traction (excluding agricultural highway use), power or heating (agricultural and domestic). Energy consumption in services is expressed as a share of total energy consumption (%). Energy consumption in services includes both commercial and public services. Energy consumption in transport is expressed as a share of total energy consumption (%). Energy consumption in transport covers all transport activity (in mobile engines) regardless of the economic sector to which it is contributing. Energy consumption in industry is expressed as a share of total energy consumption (%). Energy consumption in industry includes the following sub-sectors: iron and steel, chemical and petrochemical, non-ferrous metals, non-metallic minerals, transport equipment, machinery, mining and quarrying, food and tobacco, paper, pulp and print, wood and wood products, construction, textile and leather together with any manufacturing industry not included above. Energy consumption in other sectors is expressed as a share of total energy consumption (%). Energy consumption in other sectors includes residential consumption and all fuel use not elsewhere specified.

Non-energy material productivity is calculated as GDP generated per unit of materials consumed. Domestic Material Consumption (DMC) refers to the apparent consumption of materials; it is calculated as the sum of domestic consumption of biomass for food and feed, construction minerals, industrial minerals, metals and wood. Consumption of Biomass is expressed as a percentage of DMC. Biomass materials include biomass for food and wood. Food materials include crops (e.g. cereals, roots, sugar and oil bearing crops, fruits, vegetables), fodder crops (including grazing), wild animals (essentially marine catches), small amounts of non-edible biomass (e.g. fibres, rubber), and related products including livestock. Wood includes harvested wood and traded products made of wood (e.g. paper, furniture, etc.). Total domestic material consumption refers to the apparent consumption of materials; it is calculated as the sum of domestic consumption of biomass for food and feed, construction minerals, industrial minerals, metals and wood. Consumption of non-metallic materials is expressed as a percentage of Domestic Material Consumption (DMC). Non-metallic minerals include construction and industrial minerals. Construction minerals include primary (e.g. sand, gravel, stones, limestone, excavated soil if used) or processed (e.g. glass, cement, concrete) minerals. Industrial minerals include primary or processed non-metallic minerals (e.g. salts, arsenic, potash, phosphate rocks, sulphates and asbestos). Consumption of metals is expressed as a percentage of DMC. Metals include metal ores, metals and products make of metals. Municipal waste generated in expressed in kg per person. Municipal waste is waste collected by or on behalf of municipalities. It includes household waste originating from households (i.e. waste generated by the domestic activity of households) and similar waste from small commercial activities, office buildings, institutions such as schools and government buildings, and small businesses that treat or dispose of waste at the same facilities used for municipally collected waste.
Production-based CO2 intensity is calculated as CO2 emissions per capita (tonnes/person). Included are CO2 emissions from combustion of coal, oil, natural gas and other fuels. The estimates of CO2 emissions are obtained from the IEA’s database of CO2 emissions from fuel combustion.

### 2.4. ANFIS methodology

The ANFIS network has five layers, each of which performs a different operation during the training process (Figure 3). The ANFIS network’s key core is the fuzzy inference framework (FIS). The first layer takes in input signals and uses membership functions to translate them to fuzzy values. The bell-shaped membership function is used in this study because it has the best capability for nonlinear data regression.

![Figure 3: ANFIS structure](image)

The following is a description of bell-shaped membership functions:

\[ \mu(x) = \text{bell}(x; a_t, b_t, c_t) = \frac{1}{1 + \left(\frac{x-c_t}{a_t}\right)^{2b_t}} \]  

where \( \{a_t, b_t, c_t\} \) is the parameters set and \( x \) is input.

By multiplying the fuzzy singlas from the first layer, the second layer provides the rule's firing power. Many of the signals from the second layer are normalized in the third layer. The fourth layer is responsible for rule inference. The final layers summed all of the signals and provided a crisp output value.

ANFIS methodology was implemented in MATLAB software for the selection procedure. During selection procedure non-relevant parameters could be removed. Parameters with small relevance do not have high impact on the output. The dataset is partitioned into a training set (trn_data) and a checking set (chk_data). The function “exhsrch” represents exhaustive search procedure within the given inputs.

### 3. Results
3.1. Accuracy indices

The following are the results of the proposed model as root mean square error (RMSE), coefficient of determination ($R^2$), and Pearson coefficient ($r$):

1) RMSE

\[
\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2},
\]

(2)

2) Pearson correlation coefficient ($r$)

\[
r = \frac{n \left( \sum_{i=1}^{n} O_i \cdot P_i \right) - \left( \sum_{i=1}^{n} O_i \right) \left( \sum_{i=1}^{n} P_i \right)}{\sqrt{\left( n \sum_{i=1}^{n} O_i^2 - \left( \sum_{i=1}^{n} O_i \right)^2 \right) \left( n \sum_{i=1}^{n} P_i^2 - \left( \sum_{i=1}^{n} P_i \right)^2 \right)}}
\]

(3)

3) Coefficient of determination ($R^2$)

\[
R^2 = \frac{\left[ \sum_{i=1}^{n} (O_i - \bar{O}_i) \cdot (P_i - \bar{P}_i) \right]^2}{\sum_{i=1}^{n} (O_i - \bar{O}_i) \cdot \sum_{i=1}^{n} (P_i - \bar{P}_i)}
\]

(4)

where $P_i$ and $O_i$ are known as the experimental and forecast values, respectively, and $n$ is the total number of checking data.

3.2. ANFIS results

In the first stage ANFIS network is trained with data section in Table 1 where there are four input variables and the output is TCO2e. The main goal is to determine RMS errors of each single parameter from the Table 1 based on the TCO2e prediction. Figure 4 shows the RMSE errors of the single parameters. One can note the generated waste has the smallest RMS error hence the strongest relevance in regard to the TCO2e prediction. There are two RMS errors, for training (trn) and for checking (chk) of the ANFIS models. 50% data were used as training data while remaining 50% data were used as checking data. Each of the ANFIS model is trained with one epoch in order to determine the parameters’ relevance to the TCO2e. Based on the comparison of
the training and checking errors there is no overfitting in the ANFIS models since the training and checking errors are comparable. Figure 5 shows the optimal combination of single input and single output for the best TCO2e prediction.

Table 4 shows the RMS errors of the single parameter for OECD database. Based on the results energy intensity has the highest impact on the CO2 intensity in the OECD members.
Table 4: RMS errors of the single parameters for OECD database

| Parameter                                              | Training | Checking |
|--------------------------------------------------------|----------|----------|
| Energy productivity                                   | 1.1675   | 0.9051   |
| Energy intensity                                       | 0.2890   | 0.2700   |
| Total primary energy supply, index                     | 2.2897   | 2.2158   |
| Total primary energy supply                            | 1.4048   | 1.1236   |
| Renewable energy supply                                | 1.4174   | 0.8156   |
| Renewable electricity                                  | 1.5567   | 1.1026   |
| Energy consumption in agriculture                      | 0.7198   | 0.8032   |
| Energy consumption in services                         | 1.7271   | 1.7456   |
| Energy consumption in industry                         | 2.1346   | 1.7229   |
| Energy consumption in transport                        | 1.2553   | 1.1864   |
| Energy consumption in other sectors                    | 1.0176   | 0.9700   |
| Non-energy material productivity                       | 1.9626   | 1.8932   |
| Biomass                                                | 1.6200   | 1.9191   |
| Non-metallic minerals                                  | 2.0336   | 2.1524   |
| Metals                                                 | 1.2922   | 1.1244   |
| Municipal waste generated                              | 0.8411   | 0.7793   |

Figure 6 shows the RMS errors of the combinations of two parameters for Scottish Household waste. One can note the combination of generated and recycled wastes is the optimal combination for the TCO2e prediction. Figure 7 shows the optimal combination with two inputs and one output for the TCO2e prediction.
Based on the results for the OECD database energy intensity and biomass consumption is the optimal combination (trn=0.0777, chk=0.2759) of two parameters with the highest impact on the CO2 intensity in the OECD members. Therefore, biomass has the very high carbon impact and it has to be recycled and reused in circular economy.

Three selected parameters are extracted and new ANFIS model is generated and trained with 100 epochs. Figure 8 shows the ANFIS prediction of TCO2e index based on two selected combinations. The all data are used for ANFIS training and checking as well. In other words, ANFIS was trained with all data and then checking against the same data. There is high prediction accuracy based on three statistical indicators (r=0.977134, RMSE=0.037568, R²=0.9548).
Figure 8: ANFIS prediction of TCO2e based on the selected input combinations for Scottish Household waste

Figure 9 shows the ANFIS prediction of TCO2e index based on two selected combinations. The all data are used for ANFIS training and checking as well. In other words, ANFIS was trained with all data and then checking against the same data. There is high prediction accuracy based on three statistical indicators ($r=0.999966$, RMSE=0.019732, $R^2=0.9999$).

Figure 9: ANFIS prediction of production-based CO2 intensity based on the selected input combinations for OECD members
4. Conclusion

Since ecological and environmental sustainability are at the forefront of the economy, the circular economy is the economy for the future. The circular economy's central concept is human life's long-term viability. The circular economy may offer a way to overcome the current production and consumption model, which is limited in terms of energy resources. This economy is focused on a closed-loop system in which the primary energy and material resources are urban and industrial wastes.

The main goal of the study was to analyze the effect of waste generation and recycling on production-based CO₂ intensity based on circular economy concept. For such a purpose adaptive neuro fuzzy inference system (ANFIS) was implemented since the methodology is suitable for statistical investigation of strongly nonlinear data sample. Generated and recycled waste including biomass is the most influential factors for the production-based CO₂ intensity based on circular economy concept. The main concluding remarks could be summed as follows:

- Generated waste has high impact on the carbon dioxide emission,
- Biomass consumption has the high impact on the carbon dioxide emission,

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