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Front Pages

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Editors

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The current issue is the first of the twelfth volume of the *Athens Journal of Sciences (AJS),* published by Natural & Formal Sciences Division of Athens Institute.

Gregory T. Papanikos
President
Athens Institute

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21-24 July 2025, Athens, Greece

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Important Dates

- Abstract Submission: **1 April 2025**
- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **23 June 2025**

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Predictive Modeling of Chemical Waste Generation in Healthcare Facilities: Enhancing Waste Management Strategies

By Mohammad A. Shbool[*], Yara Altarawneh[±], Raghad Bani Hamad[°], Rand Alqa'aydeh[•], Mohammad D. Al-Tahat[♦], Thahabia Abedeljawad[♥] & Mohammed J. K. Bashir[♠]

The escalating generation of chemical waste in healthcare facilities is a pressing concern, particularly during rapidly spreading epidemics. This study proposes a system dynamics model to predict hospital chemical-waste generation rates. The model incorporates various variables, such as patient arrival and departure rates, to provide accurate estimations of waste generation. A case study conducted at a hospital validates and demonstrates the proposed model's practical application. The findings reveal that specific departments, such as Main Operations, Obstetrics, and Catheter, significantly influence healthcare chemical-waste generation rates. Additionally, the Tissue Department plays a substantial role. This research has two important implications. Firstly, it offers valuable insights into the complex factors affecting waste generation in healthcare facilities, identifying the departments that contribute most to the problem. Secondly, it provides waste management departments with a insights for capacity planning, scheduling, and resource allocation. Hospitals can enhance their waste management practices, leading to improved environmental sustainability and better public health outcomes. This study's ability to anticipate chemical waste generation and drive the development of comprehensive and long-term waste management programs is highlighted by its identification of the most significant departments in generating chemical waste. This study blends predictive intelligence with pragmatic insights, emerging as a crucial instrument for tackling the severe difficulties posed by the rising flow of chemical waste. It ultimately protects both individual well-being and the balance of the ecosystem.

Keywords: *system dynamics, chemical waste, healthcare facilities*

Introduction

Human activities, modern lifestyles, and everyday consumption habits have resulted in massive waste over the last few decades (Oweis et al. 2005). The waste produced by activities at healthcare facilities carries a greater risk of illness and harm than other waste types (Ciplak and Barton 2012). Assessing and prioritizing healthcare waste hazards is a paramount problem. Thus, highlighting the

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importance of waste management strategies, policies, and corrective actions to mitigate the adverse effects of healthcare waste is critical (Navazeshkhah et al. 2019, ALMashaqbeh and ALKhamisi 2023). The waste released in healthcare facilities can be divided into general and hazardous waste (Kerdsuwan and Laohalidanond, 2015). Most healthcare waste (75–90%) is non-risk (also known as general waste) (Eleyan et al. 2013). The remaining 10–25% of healthcare facility waste is considered infectious and dangerous, posing several health hazards (Chaerul et al. 2008, Mol et al. 2022), and should be carefully managed and disposed according to (Neves et al. 2022). Waste can be considered hazardous if it checks one or more characteristics: ignitability, corrosivity, reactivity, and toxicity (Polprasert and Liyanage 1996). This study will focus on Chemical healthcare waste, which is hazardous since it is an ignitable type of waste.

The main types of chemical waste in healthcare facilities are categorized into formaldehyde, photographic fixing, and developing solutions; solvent wastes that contain halogenated and non-halogenated compounds; and wastes from materials with high heavy-metal contents (Ciplak and Barton 2012, Mohiuddin 2018, Laz et al. 2019).

Formaldehyde is considered a substantial chemical waste source, used in pathology, autopsy, dialysis, embalming, and nursing facilities, as well as to clean and disinfect equipment (such as hemodialysis or surgical equipment), preserve specimens, and disinfect liquid infectious waste (World Health Organization 2014). Formaldehyde is a virtually colorless gas with an overpowering stench at room temperature. In markets, formaldehyde is often sold as 30 to 50 percent (by weight) aqueous solutions of the hydrated form, also known as formalin (Lyapina 2012). It is considered a very toxic material, putting the lives of those who deal with it at risk. Safe disposal of this toxic waste is a requirement; thus, predicting the waste volume of such chemical material needs to be investigated. This helps to manage the waste-disposing system more efficiently to avoid excessive contact with this toxic chemical.

Increasing the potential risk associated with chemical healthcare waste is the existing gap in knowledge, training, and consciousness among healthcare personnel about safe chemical healthcare management; despite the availability of clearly stated standards, it leads to unsafe practices, exposing both health and the environment to potential hazards (Sharma 2010).

Due to the risks posed by these types of waste, additional care must be taken in collecting, storing, transmitting, and disposing of chemical healthcare waste. The waste management system is a combination of these four waste processing cycles. In waste management analyses, the amount of future healthcare waste is crucial. The amount of waste generated must be known with great precision to form an accurate strategy for disposal. This strategy is based on estimating the volume of the waste in terms of all related variants, including the dynamism.

Our study focuses on Chemical healthcare waste, which is hazardous since it is an ignitable type of waste. Predicting the amount of healthcare waste generation rate is vital to an efficient hospital's planning and procedure. Therefore, this paper aims to develop a prediction model to anticipate the future status of chemical waste

generation in hospitals. The model will be validated and studied based on a case study; thus, the current study will be conducted in a hospital.
The theoretical and practical contributions in developing this model for chemical waste prediction in healthcare facilities can be summarized as follows.

Introducing a model for chemical waste generated amounts prediction in healthcare facilitates.
Identifying the system's complexity by investigating the factors affecting chemical waste and their relations.
As a practical implication, the developed model helps the waste management department to plan recycling operations and resource allocation. Starting recycling activities is a positive start toward tackling the issues related with hazardous waste and environmental damage (McCoy et al. 2017).

Literature Review

Various methodologies were used to predict hazardous waste in general, particularly healthcare chemical waste. For example, the multiple linear regression (MLR) technique was used in some studies, such as (Thakur and Ramesh 2018, Golbaz et al. 2019, Çetinkaya et al. 2020). Machine learning approaches such as artificial neural networks (ANN), fuzzy logic-artificial neural networks (ANFIS), and support vector regression (SVM) have evolved and been adopted in such areas. They have grown prominent in recent years due to their high flexibility and demonstrated prediction skills (Golbaz et al. 2019). Some studies used Artificial neural networks (ANN), including (Karpušenkaitė et al. 2016). Other studies used Autoregressive Integrated Moving Average (ARIMA), such as (Ceylan et al. 2020). In some studies, researchers included both artificial neural networks (ANNs) and multiple linear regression (MLR) predictor models such as (Jahandideh et al. 2009). Support Vector Regression (SVR) and Grey Modelling (1,1) were also used in many studies.
In a study conducted on the European Union (EU) in 2018, the general regression neural network (GRNN), which is a form of artificial neural network (ANN), is used to predict the annual quantities of hazardous chemical and healthcare waste. Their study has considered chemical waste, unlike many other studies that predicted the amounts of hazardous waste in healthcare facilities. Although this study predicts the quantities of waste produced, it generally studies chemical waste. Still, it is not associated with healthcare activities and does not examine the different types of healthcare hazardous waste separately (Adamović et al. 2018).
More studies in different systems considered simulating toxic waste production (N. et al. 2010) illustrate how computer-based modeling is used to track and manage environmental impacts. Such modeling can provide insights into complex interactions within ecosystems and help avoid the health and environmental risks associated with insufficient waste disposal procedures, resulting in a cleaner and safer environment.

One of the main methods used in waste prediction is System Dynamics (SD). It is a modeling methodology introduced by "Jay Forrester" in the 1960s based on feedback, a substantial element in analyzing systems. It models complex systems and allows easier decision-making and conceptualization when evaluating different scenarios. System Dynamics can adequately track the impacts of changes in subsystems and their relationships and represent and express them (Chaerul et al. 2008). System dynamics is introduced as a modeling and simulation tool for long-term decision-making analysis of industrial management challenges. Forrester also concluded that the mathematical concepts of control theory do not apply to managed systems since they are significantly more complex than engineering challenges. As a result, the final stage of Forrester's intellectual achievement was to design the structure of specialized computer simulation languages so that system dynamics computations could be conducted quickly and efficiently (Coyle 1997). The importance of simulation models rests in their adaptability and capacity to handle complex system behavioral features.

Many studies have used system dynamics to represent waste management systems, but using prediction models to represent chemical healthcare waste is rarely found. For example, researchers (Ciplak and Barton 2012) used SD to develop a model to help select and plan future treatment capacity. The case study location was Istanbul, Turkey. Observations and interviews were done in Istanbul over three months to discover the factors driving healthcare waste generation. A system dynamics model was used to develop a healthcare waste management model using the software package Vensim® PLE Plus. Authors (Zanjani et al. 2012) implemented the system dynamics method in solid waste management. Other studies, like (Singh et al. 2022), investigated various socioeconomic and environmental parameters on medical waste generation.

In Chaerul et al. (2008), using the Stella® software package, a hospital waste management model based on system dynamics was developed to determine the interaction among variables in the system. The city of Jakarta, Indonesia, was chosen as a case study. The main variables considered in their studies model were the number of hospital beds and the NIMBY (not in my backyard) syndrome, which suggests that individuals support a project as long as it is not in their backyard (Uji et al. 2021). The main idea of this study is that segregating medical waste and infectious waste treatment before disposal must be done correctly by hospital management.

In Al-Khatib et al. (2016), the researchers focus on the current state of waste generation without anticipating and predicting future generation rates or waste treatment and disposal costs. Although the model represents medical waste, it uses different variables than the ones this study uses, and the type of waste predicted is more general than what this study considers. The variables used in their study included inpatients and outpatients in different hospitals. However, in addition to inpatients and outpatients, our current study had detailed data on each floor and unit. Our model also explicitly predicts the chemical waste generation rate and the type of floor's influence on the generation rates.

In Eleyan et al. (2013), the researchers used system dynamics to anticipate generated medical and solid waste in a developing metropolitan environment. The study suggests that when traditional statistical least-squared regression methods cannot predict the generation of these types of wastes, a new forecasting approach may cover a variety of possible causative models and track inevitable uncertainties by separating the wastes into categories (metals, cardboard, paper, textiles, plastics, glass, and other materials).

Understanding the dynamics of waste generation is paramount in the pursuit of efficient waste management. Previous studies have primarily focused on general hazardous waste prediction and healthcare waste in broader terms. Our study, however, delves into the specific realm of healthcare chemical waste due to its inherent toxicity, necessitating meticulous handling and disposal strategies. To achieve this, we aim to construct a prediction model using the System Dynamics (SD) approach, allowing for precise volume forecasts and informed waste management strategies. This modeling approach considers various factors, including the type of department treatment indicated by floors, providing comprehensive insights into chemical waste generation rates. We emphasize the need for dedicated modeling by distinctly addressing healthcare chemical waste, considering the unique characteristics and associated risks that demand specialized disposal strategies. Integrating our predictive model into waste management practices will empower healthcare facilities to efficiently plan resources and manage hazardous waste more safely and sustainably.

Methodology

This section presents the model development framework of the chemical waste prediction model using the systems dynamics approach. It also includes the causal loop diagram that leads to the development of the final systems dynamics model. This diagram considers the patients' population dynamics, including the impact of the arrival and departure rates of patients, leading to the number of hospital patients and the waste weights collected from each floor in the hospital.

The following section presents the development of the causal loop diagram.

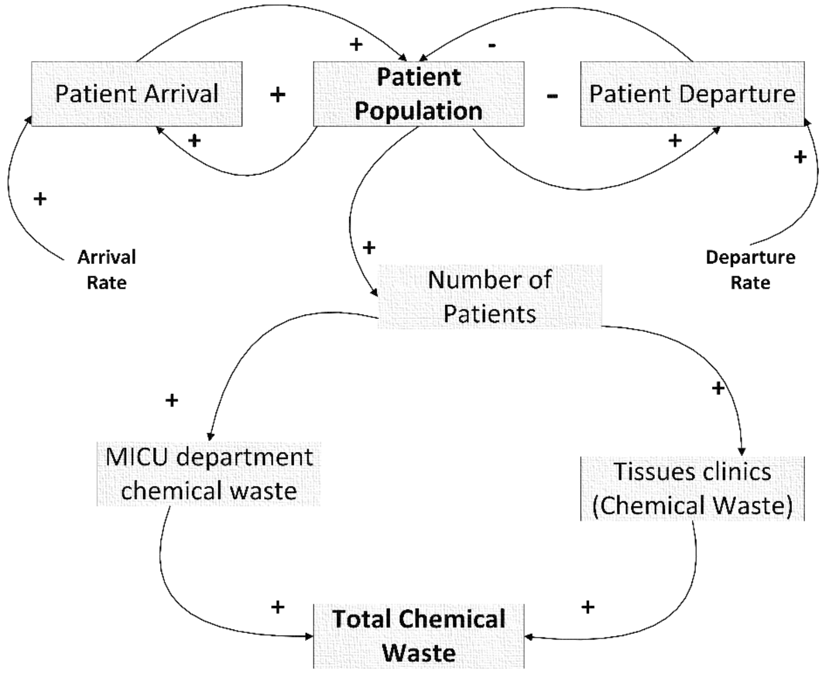
Causal Loop Diagram

The first step in developing an SD model is to create the causal loop diagram. The causal-loop diagrams were not usually used in early system dynamics modeling. However, such diagrams provide a way to make system dynamics more approachable to a broader audience. This step is also referred to as systems thinking.

The diagram represents the causal relationships between the relevant variables (factors). It is a representation of the main feedback using arrows and elements (casual links) that connect the signs, either positive (+) or negative (-), that represents the state of the relationship between different elements. If the symbol is positive (+), all effects head in the same direction. As one aspect increases, the other increases as well. A negative (-) sign indicates that the two elements are heading in opposite directions, with one rising and the other declining.

After that, depending on the number of positive (+) or negative (-) signs in the loop, the entire loop is given a sign, either positive (+) or negative (-). The loop is given a positive (+) sign if the number of negative (-) signs is even, indicating that the system is unstable. If the number is odd, the loop is given a negative (-) sign, indicating that it is in equilibrium.
The causal loop diagram is built by determining the variables intended to be used in the model. A sample of the causal loop diagram created is shown in Figure 1. As shown in Figure 1, the patients' arrival and departure rates affect the patient population. This population affects the arrivals and departures numbers in return, which is called a feedback loop. The population affects the number of patients in the case study hospital, as the number increases when the population increases. The chemical waste is directly related to the net number of patients.

Figure 1. *Causal Loop Diagram - Sample from*



The chemical waste quantities data was obtained from the hospital records. A sample of one year for the waste quantities was obtained, including the floor name, day of collection, type of waste (chemical solid/ chemical formaldehyde), and weights in Kg. The total waste (chemical solid/ chemical formaldehyde) for each floor in the hospital and outpatient clinics is calculated using the collected data to find the rate each floor produces in (kg/bed/day).
After developing this diagram, the next stage is developing the system dynamics model, which is introduced in the next section.

System Dynamics Model

The system dynamics model was developed to predict the amount of chemical waste the hospital generates, explicitly focusing on formalin waste produced by surgical floors. This chemical material is primarily used as an antiseptic, disinfectant, and histology fixative, and it is toxic to the human body if it is misused.

The model considers the number of patients in the hospital as the primary driver of waste production on each floor, which is calculated using previously explained equations. The "population" stock is directly linked to the number of arrivals and departures of patients, which is determined based on the patients' population. Each floor and department in the hospital has a specific waste production rate per patient, which is included in an equation connecting these variables to produce an accurate prediction of the total chemical waste generated. The model accounts for the fact that not all floors in the hospital create all types of waste, and only the floors that generate the chosen kind of waste (solid and Formalin) are included.

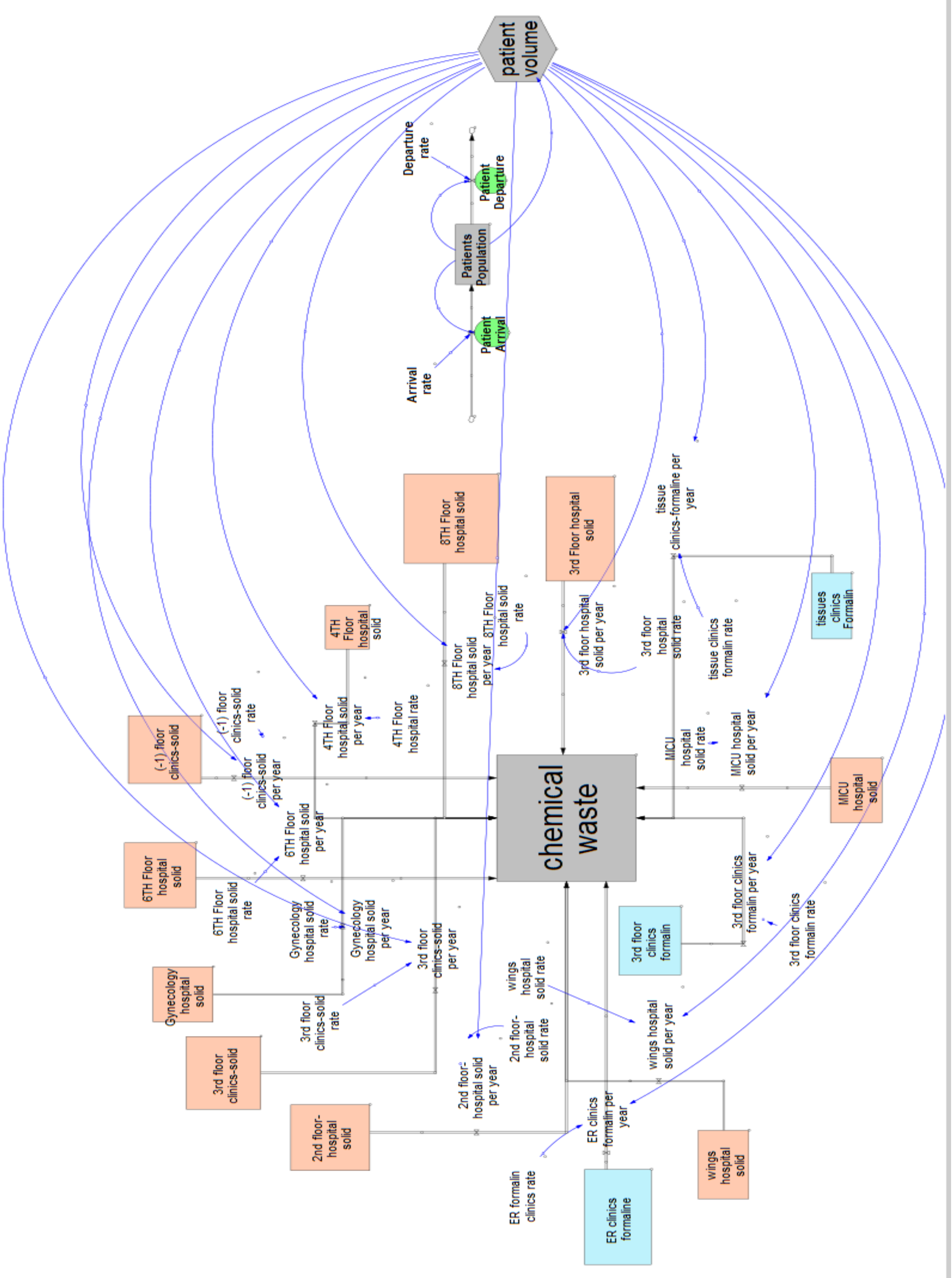
The model employs orange squares to represent the stock of solid chemical waste produced and blue squares to represent the stock of formalin chemical waste produced by specific floors in the hospital. Considering each floor's generation rates, these stocks are summed and directed into a single "Chemical waste." Each floor has a blue arrow directed toward it, originating from the "Patient volume" variable representing the number of patients in the hospital. This arrow represents the flow of patients into that particular floor and their corresponding impact on the production of chemical waste. The construction of this system dynamics model is illustrated in Figure 2. The system includes a stock for the chemical waste on each floor, directed towards the total chemical waste stock via an arrow with flow in the middle. Each floor is also associated with a variable connected to the waste generation rate, depicted by a blue connector arrow.

The hospital floors represented in the model consist of different departments, each with a distinct function. Table 1 presents the departments present on each floor. The idea is determining which floors and departments produce the most chemical waste.

Table 1. *Departments of Every Floor in the Hospital that are Considered in this Study*

Floor Name	**Departments**
3rd floor clinics (outpatients)	Dialysis, Blood bank, clinical laboratory, gynecology clinics.
-1 floor clinics (outpatients)	Blood disease, Nerve clinics, psychology, diabetes, and pediatrics clinics.
2nd-floor Hospital (Inpatients)	Surgery patient's rooms.
3rd-floor Hospital (Inpatients)	Pre-operative rooms and ICU.
4th-floor Hospital (Inpatients)	Surgery patient's rooms.
6th-floor Hospital (Inpatients)	Internal Medicine Department and Pulmonary Function Laboratories
8th-floor Hospital (Inpatients)	Pediatrics.
ER clinics (outpatients)	ER clinics
Tissues clinics (outpatients)	Tissues clinics
Gynecology hospital (Inpatients)	Gynecology department at the hospital
MICU hospital (Inpatients)	MICU of the hospital
Wings Hospital (Inpatients)	Wings of the hospital

Figure 2. *Chemical Waste SD Model*



Model Mathematical Relationships

In order to define the relationships between the system dynamics components, mathematical equations in the stock-and-flow diagrams are used to represent the feedback structure. All the parameters and variables are calculated using the equations explained below.

Patient Population:

Patient population **(**Ƥ**)** is composed of the number of patient arrival influenced by the arrival rate **(**$\boldsymbol{\Gamma_A}$**)** and the number of patient departures influenced by the departure rate **(** $\boldsymbol{\Gamma_D}$**)**. Arrivals are calculated by multiplying the patients' population **(**Ƥ**)** by the arrival rate **(**$\boldsymbol{\Gamma_A}$**);** similarly, departures are calculated by multiplying the patient population **(**Ƥ**)** by the departure rate **(** $\boldsymbol{\Gamma_D}$**) as shown in equations** (1-3).

$$\boldsymbol{P_t = P_{t-1} + (Arrivals - Departure)} \quad (1)$$
$$\textbf{Arrivals} = \text{Ƥ} \times \boldsymbol{\Gamma_A} \quad (2)$$
$$\textbf{Departures} = \text{Ƥ} \times \boldsymbol{\Gamma_D} \quad (3)$$

The mean amount of waste for each floor (kg/day):
The mean amount of waste on each floor per day is calculated by adding all waste weights (Kg) for a specific floor and dividing it by the total number of days, as shown in Equation (4).

$$\overline{X} = \frac{\sum \boldsymbol{X}}{\boldsymbol{N}} \quad (4)$$

where $\bar{X}$ (Kg/day) represents the mean waste weight in (Kg) of each floor, $\sum \boldsymbol{X}$ is the total waste weight (Kg) produced from the floor, and N is the total number of days of the case study duration (day). This Equation is repeated to all floors before being incorporated into the rate equation.

Rate of waste generation for each floor (Kg/bed/day):
The chemical (formalin/solid) waste generation rate on each floor is essential in developing the system dynamics model. According to the data available, the waste generation rate ($\boldsymbol{\Gamma_p}$) (Kg/bed/day) is calculated by dividing the mean amount of waste for a floor ($\bar{X}$) (Kg/day) by the total number of patients who are treated in the case study hospital ($\sum \boldsymbol{p}$) (bed). Equation (5)

$$\boldsymbol{\Gamma_p} = \frac{\boldsymbol{\bar{X}}}{\sum \boldsymbol{p}} \quad (5)$$

Another essential formula used later in the results is the percentage of change (%$\boldsymbol{\Delta}$) used in the sensitivity analysis. This value is calculated by dividing the original value of either cost or weight ($\boldsymbol{V_O}$) with the new value resulting from doubling one variable ($\boldsymbol{V_N}$), Equation 6.

$$\%\boldsymbol{\Delta} = \frac{\boldsymbol{V_N - V_O}}{\boldsymbol{V_O}} * \mathbf{100\%} \quad (6)$$

Accelerated rate of change
The enhanced rate of change was determined by subtracting the prevailing rate from the preceding rate and then accelerating by a decadal amplification factor, see Equation (7).

$$\boldsymbol{\alpha} = (\%\boldsymbol{\Delta}_{N} - \%\boldsymbol{\Delta}_{O}) \times \boldsymbol{\lambda} \qquad (7)$$

where "α" represents the accelerated rate of change, "λ" represents the amplification factor, and "$(\%\boldsymbol{\Delta}_{N} - \%\boldsymbol{\Delta}_{O})$" represents the annual disparity in alterations.

Recognizing the significant increase in chemical waste generation is crucial for resource allocation and effective waste management planning in healthcare facilities. It also helps evaluate environmental impacts and promote sustainable waste solutions. Analyzing the rate of change addresses health and safety issues and ensures compliance **with chemical waste management** regulations, preventing legal and operational complications.

Case Study

Data Collection

This case study was conducted at the University of Jordan Hospital in Amman, Jordan, over one year (March 2021 to March 2022). The hazardous waste generated at the hospital was categorized into two types: medical waste and chemical waste, which were then collected and weighed by the staff from the medical waste unit on each floor, including the outpatient clinics.

Having a medical waste treatment unit and being one of the largest hospitals in Jordan, this healthcare facility was an ideal place to perform this study. The hazardous waste unit also collected waste data from each department separately, providing valuable information for the study. The data considered in this case study included the weights of chemical waste generated over one year, the number of hospital patients, and the patient population considering the number of arrivals and departures during the same period. Table 2 presents the data used to predict the total amount of chemical waste the hospital will generate over the next ten years.

Table 2. *Input Data (Rate of Change and Initial Weights for Each Floor)*

Floors	Rate of change	Chemical waste weights (Kg)
UG_C-S	6.39E-05	44.7
$2G_H$-S	3.52E-05	24.65
$3G_C$-F	0.0004432	310.2
3 G_C-S	0.0004137	289.55
3 G_H-S	6.43E-06	4.5
$4G_H$-S	3.76E-05	26.35
$6G_H$-S	8.98E-05	62.85
$8G_H$-S	2.14E-06	1.5
ER_C F	2.67E-05	18.7
Gynecology $_H$ S	3.71E-06	2.6
$MICU_H$ S	9.50E-06	6.15
tissue G_C F	0.0022505	1575.65
wings $_H$ S	5.86E-06	4.1

Validation and Verification

The system dynamics model was verified by testing and evaluating if the model was implemented correctly. The model's compatibility with the actual system structure and the entered data were checked by experts from the hospital. The verification was done by walking through the model and checking the flow logic. Moreover, Since Vensim software offers logical checks, the model's verification is emphasized when the model is executed. When there are any dimensional inconsistencies or mistakes made when creating the model equations, the software discloses an error that prohibits the model from running.
One of the challenges in using simulated data for scientific research is the possibility of inaccuracies in the mathematical models that support the simulations. These mistakes can produce incorrect or misleading findings (Pavin and Knežević 2023), this can only be solved by validating the model.The validation compares the model's results with the actual system results (data). The case study data was collected from March/2021 to March/2022. Therefore, to validate the model, a comparison was made between the predicted results of the total chemical waste produced and the true results provided by the hospital for the following month (May/2022). Total chemical waste weight predicted for the next year by the model is 2402.64 Kg/year, which is 200.22 kg/month on average. According to the hazardous waste unit staff at the hospital for May/2022, the actual value was 194.3 Kg, which indicates an error of 2.95%. This percentage is assumed to be acceptable, indicating the model's validity.

Model Run

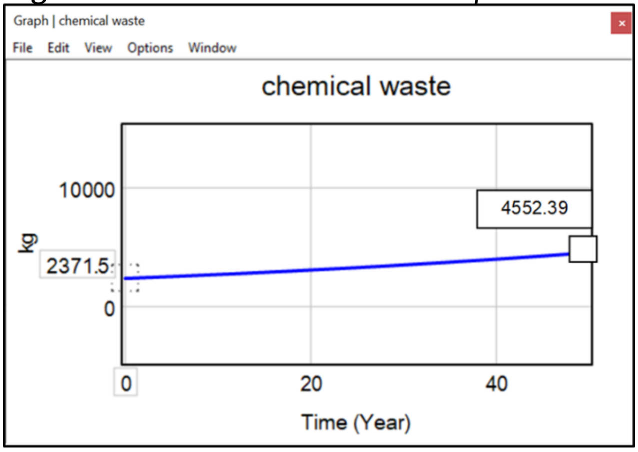
After the developed system dynamics model has been run, the predicted values of the total chemical waste, the total number of patients in the hospital, and the number of arrivals and departures are shown in Table 3. It shows that the total chemical waste increases as the patient population increases.

Table 3. *The Prediction Results for the Next Ten Years*

Year	Patient Population	Number of Arrivals	Number of Departures	Number of patients in the hospital	Total Chemical waste (Kg)
2021	10300000	171268	36050	699925	2371.5
2022	10435200	173517	36523	709114	2402.64
2023	10572200	175795	37002	718423	2434.18
2024	10711000	178103	37488	727854	2466.13
2025	10851600	180441	37980	737410	2498.51
2026	10994100	182810	38479	747090	2531.31
2027	11138400	185209	38984	756898	2564.54
2028	11284600	187641	39496	766835	2598.21
2029	11432800	190104	40014	776902	2632.32
2030	11582900	192600	40540	787101	2666.87
2031	11734900	195128	41072	797434	2701.89

Figure 3 shows predicted chemical waste quantities for the next 50 years. It indicates the increasing rate in the produced amounts of waste depending on the change in patients' population, rate of departures and arrivals, and the number of patients in the hospital.

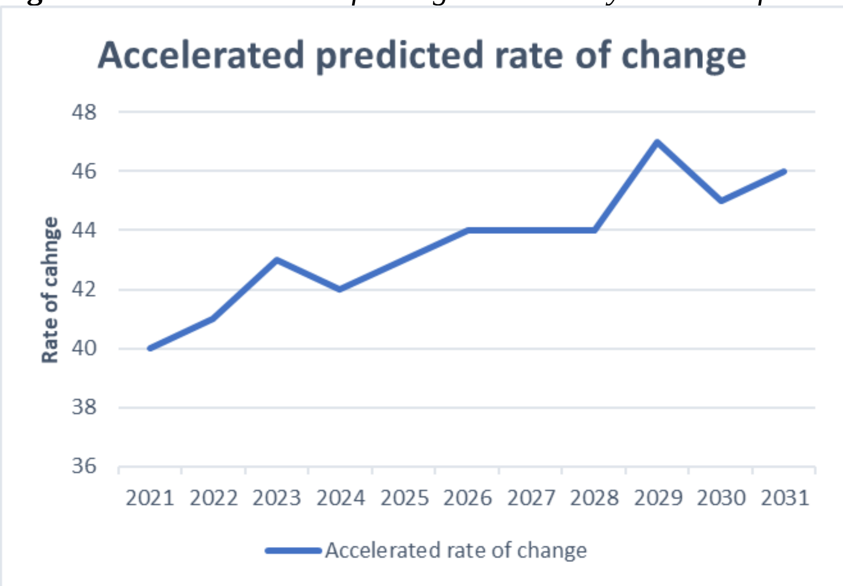
Figure 3. *Chemical Waste Prediction for the Next 50 Years*



Accelerated predicted Rate of Change

The accelerated rate of change predicted by the model for the next decade, Using an amplification factor of 10, can be represented in Figure 4.

Figure 4. *Accelerated Rate of Change Predicted by the Model for the Next Decade*



The rate change sequence resulting from the model, spanning from 0.4 to 0.47 within the initial decade, demonstrates the dynamic effect of numerous parameters on generation rates. Different variations emphasize the complex interplay of other elements, such as the number of arrivals and departures and the comprehensive array of distinct departments considered on a substantial scale, illustrating the wide range of their influence on the overall rate of change. The data emphasizes the importance of considering a wide range of factors when studying variations in generation rates, emphasizing the complexities of the observed patterns.

Experimental Design

This section aims to design and run different scenarios to identify the impact of changing various parameters of the waste prediction model on its robustness.

First Scenario: Increase the Usage of Formalin in Medical Procedures for a New Surgical Breakthrough

This scenario discusses the impact of increasing the amounts of Formalin usage in a surgical breakthrough on the quantity of Formalin wasted. As shown in Figure 5**Error! Reference source not found.**, the difference in the chemical waste generated is significant compared to the previously predicted value by the developed model. For example, the initial expected value for the second year is 1,954 Kg, while the new predicted value of the scenario is approximately 3,909 Kg. Although the new value is significantly higher, this prediction would be helpful in terms of redesigning the chemical waste units, especially the Formalin saving unit, because Formalin is considered a very poisonous material and harmful to the environment.

Figure 5. *Scenario I Vs Original Model Predictions*

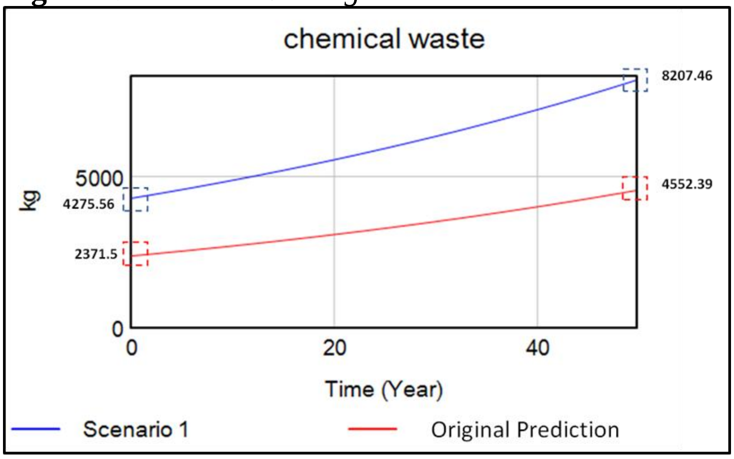


Figure 5**Figure 5** shows a difference between the original prediction results obtained by running the developed SD model and the first scenario results. This is attributed to the fact that by increasing the waste rate of Formalin, the difference between them will increase. The modified rates and the obtained predicted amounts of Formalin are shown in Table 4. Also, a comparison is made between the original prediction and the one resulting from the scenario.

Table 4. *Scenario I Detailed Results*

Years	3rd-floor clinics formalin rate: Scenario 1	3rd floor clinics formalin rate: Original	ER formalin clinics rate: Scenario 1	ER formalin clinics rate: Original	Tissue clinics formalin rate: Scenario 1	Tissue clinics formalin rate: Original
	0.000886	***0.000443***	***5.34E-05***	***2.67E-05***	***0.004501***	***0.00225***
	Predicted weights for each floor					
2021	***620.4***	***310.2***	***37.4***	***18.7***	***3150.3***	***1575.2***
2022	***628.5***	***314.3***	***37.9***	***18.9***	***3191.7***	***1595.8***
2023	***636.8***	***318.4***	***38.34***	***19.2***	***3233.6***	***1616.8***
2024	***645.2***	***322.6***	***38.9***	***19.4***	***3276.0***	***1638.0***
2025	***653.6***	***326.8***	***39.4***	***19.7***	***3319.0***	***1659.5***
2026	***662.2***	***331.1***	***39.9***	***20.0***	***3362.6***	***1681.3***
2027	***670.9***	***335.5***	***40.4***	***20.2***	***3406.7***	***1703.4***
2028	***679.7***	***339.9***	***40.9***	***20.5***	***3451.5***	***1725.7***
2029	***688.6***	***344.3***	***41.5***	***20.8***	***3496.8***	***1748.4***
2030	***697.7***	***348.8***	***42.1***	***21.0***	***3542.7***	***1771.3***
2031	***706.8***	***353.4***	***42.6***	***21.3***	***3589.2***	***1794.6***

Scenario II: Increasing the Production of Solid Chemical Waste

In the second scenario, only the rates of the floors that produce solid chemical waste are increased. The SD model is then simulated after changing the rates for every floor to identify the impact of waste rate on the predicted waste volume. Figure **6** 6 compares the amount of waste expected of the original and the second scenario for the next 50 years.

Figure 6. *Scenario II Vs. Original Model Predictions*

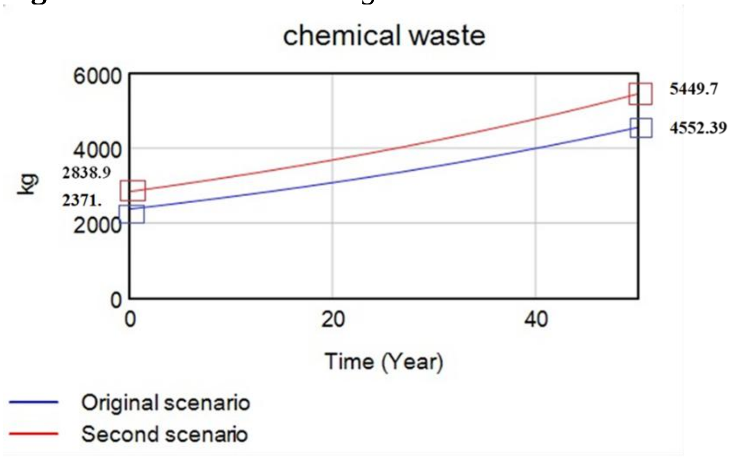


Table 5 shows the waste volume predicted in the second scenario for each floor as well as the doubled rates that were implemented in the model.

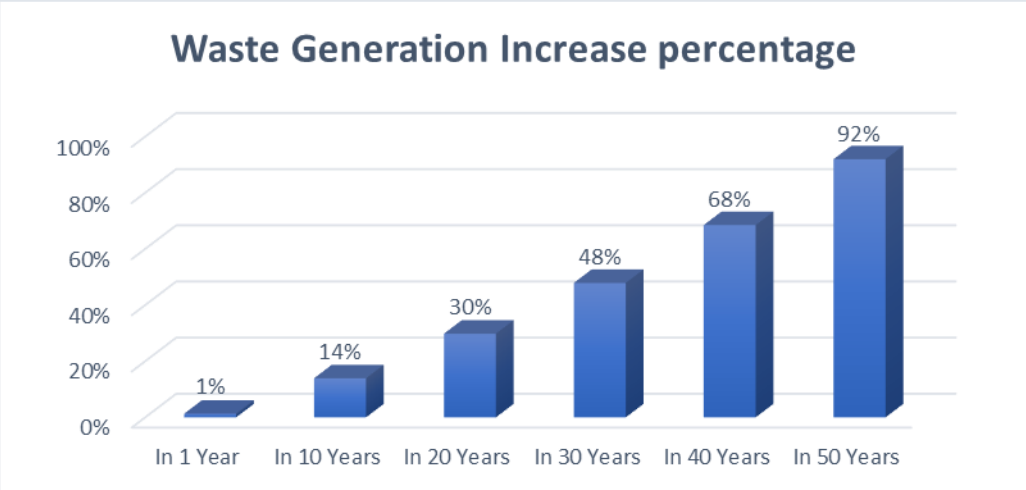
Table 5. *The Rates and Predicted Amount of Each Floor for the Second Scenario*

Years	(-1) floor clinics-solid rate.	2nd floor. Hospital solid rate.	3rd floor clinics solid rate.	3rd floor hospital solid rate.	4TH Floor hospital rate.	6TH Floor Hospital solid rate.	8TH Floor hospital solid rate.	Gynecology hospital solid rate.	MICU hospital solid rate.	Wings Hospital's solid rate
	0.000127728	7.04E-05	0.000827374	1.29E-05	7.53E-05	0.000179591	4.29E-06	7.43E-06	1.90E-05	1.17E-05
	Predicted weights for each floor									
2021	89.4	49.3	579.1	9.0	52.7	125.7	3.0	5.2	13.3	8.2
2022	90.6	49.9	586.7	9.1	53.3	127.3	3.0	5.2	13.4	8.3
2023	91.7	50.6	594.4	9.2	54.0	129.0	3.0	5.3	13.6	8.4
2024	92.9	51.2	602.2	9.3	54.8	130.7	3.1	5.4	13.8	8.5
2025	94.1	51.9	610.1	9.4	55.5	132.4	3.1	5.4	14.0	8.6
2026	95.4	52.6	618.1	9.6	56.2	134.1	3.2	5.5	14.1	8.7
2027	96.6	53.3	626.2	9.7	56.9	135.9	3.2	5.6	14.3	8.8
2028	97.9	54.0	634.4	9.8	57.7	137.7	3.2	5.6	14.5	8.9
2029	99.2	54.7	642.7	9.9	58.4	139.5	3.3	5.7	14.7	9.1
2030	100.5	55.4	651.2	10.1	59.2	141.3	3.3	5.8	14.9	9.2
2031	101.8	56.1	659.7	10.2	60.0	143.2	3.4	5.9	15.1	9.3

Escalation of Waste Production Percentage

The exponential trend of increased waste generation creates a persuasive picture of the evolving risk when addressing chemical waste. Figure 6 shows the estimated increase in chemical waste production in the next 50 years.

Figure 7. *The Estimated Increase in Chemical Waste Production in the Next 50 Years*



In less than a decade, a 14% rise in the output of this chemical waste is predicted. This pace of change, however, accelerates substantially, striking 30% over two decades and nearly doubling to 48% in the following ten years. The situation's urgency becomes apparent as time passes, with the percentage rise reaching 68% after 40 years. Most importantly, the figures demonstrate a stunning 92% rise in chemical medical waste creation over 50 years.

Conclusion

The generation of healthcare chemical waste has significantly increased in recent decades due to global population growth and the expanded use of chemicals in the medical field, particularly in laboratories. This escalating trend poses substantial risks to human life if the waste is improperly managed and disposed of. A system dynamics (SD) model was developed to forecast the volume of chemical waste generated in a healthcare facility, considering patient arrival and departure rates across different departments. System dynamics is a powerful modeling approach that enables an understanding of complex, dynamic systems and their interdependencies.

The University of Jordan Hospital was chosen as a case study to validate the effectiveness of the SD model in predicting the chemical waste generated in the upcoming decade. By utilizing system dynamics, the model aims to alleviate the problem of excessive accumulation of chemical waste, whether in solid or liquid form, by reducing costs and achieving optimal efficiency throughout the disposal process. Since chemical waste is highly toxic, utmost precautions must be taken during storage and transportation before disposal.

This study demonstrates that the developed system dynamics model considers multiple factors influencing waste volumes, such as departure and arrival rates. By capturing the dynamic relationships between these factors and waste generation, the model provides valuable insights into the potential changes in the total amount of waste a hospital generates. The results indicate an increase in chemical waste generation over the forecast period of 10 years, reaching 2701.89 kg by 2031. A 50-year forecast shows that the projected waste volume is 4552.39 kg.

In the year of the study (2021), the total amount of waste generated by the University of Jordan Hospital was recorded as 2371.5 kg, with liquid waste (Formalin) accounting for 1904.05 kg and solid waste amounting to 467.45 kg. While the quantity of chemical waste generated may not be enormous, the critical issue lies in its highly hazardous nature, necessitating specific storage and disposal procedures to ensure the safety of both staff and patients. A system dynamics model allows for a comprehensive understanding of the underlying dynamics and interdependencies in healthcare chemical waste generation, facilitating effective waste management strategies.

With an amplification factor of 10, the model's forecasted rate shifts from 0.4 to 0.47 within a decade. This dynamic demonstrates the impact of various variables on generation rates, emphasizing the importance of considering multiple factors to understand observed trends.

A concerning trend in terms of increasing chemical waste is expected according to the predicted results of the model. Over a decade, the growth rate is 14%, rising to 30% over two decades and 48% in the following ten years. The proportion then jumps to 68% after 40 years, representing an astounding 92% growth over a half-century. These estimates highlight the critical importance of implementing rapid and efficient waste management methods.

The model's ability to target departments with the largest chemical waste generation adds significance to the study, increasing its prediction capability and improving its importance in developing long-term waste management plans. The study emphasizes the necessity of establishing effective strategies for tackling the adverse effects of chemical waste on human health and the environment in light of growing waste rates. By combining predictive skills with practical insights, this research is a critical tool in solving the urgent concerns resulting from increasing chemical waste, eventually preserving the safety of both people and the ecosystem.

Acknowledgments

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Appendix: Equations and Rates Implemented in Vensim

Model Mathematical Equations

Patient Population
$P_t = P_{t-1} + (Arrivals - Departure)$
$Arrivals = \text{Ƥ} \times \Gamma_A$
$Departures = \text{Ƥ} \times \Gamma_D$
The mean amount of waste for each floor (kg/day):
$\bar{\mu} = \frac{\sum \boldsymbol{X}}{\boldsymbol{N}}$
Rate of waste generation for each floor (Kg/bed/day):
$\boldsymbol{\Gamma_p} = \frac{\bar{\mu}}{\sum \boldsymbol{p}}$
The percentage of change (%$\boldsymbol{\Delta}$
$\%\boldsymbol{\Delta} = \frac{\boldsymbol{V_N} - \boldsymbol{V_O}}{\boldsymbol{V_O}} * \mathbf{100\%}$
Accelerated rate of change
$\boldsymbol{\alpha} = (\%\boldsymbol{\Delta_N} - \%\boldsymbol{\Delta_O}) \times \boldsymbol{\lambda}$

Software Related Equations and Rates

(01) UG_C-S / Y=
$\boldsymbol{p}$V* UG_C-S **Γ**
Units: kg

(02) UG_C-S **Γ=**
6.3864e-05
Units: kg/person

(03) UG_C-S=
UG-S / Y
Units: kg

(04) $2G_H$-S / Y=
$\boldsymbol{p}$V*2G-S **Γ**
Units: kg

(05) $2G_H$-S **Γ**=
3.52181e-05
Units: kg/person

(06) $2G_H$-S=
$2G_H$-S / Y
Units: kg

(07) $3G_C$-F / Y=
$\boldsymbol{p}$V*$3G_C$-F **Γ**
Units: kg

(08) $3G_C$-F **Γ**=
0.00044319
Units: kg/person

(09) $3G_C$-F=
$3G_C$-F / Y
Units: kg

(10) 3 G_C-S / Y=
pV*3 G_C-S **Γ**
Units: kg

(11) 3 G_C-S **Γ**=
0.000413687
Units: kg/person

(12) 3 G_C-S=
3 G_C-S / Y
Units: kg

(13) 3 G_H-S / Y=
pV*3 G_H-S **Γ**
Units: kg

(14) 3 G_H-S **Γ**=
6.42926e-06
Units: kg/person

(15) 3 G_H-S=
3 G_H-S / Y
Units: kg

(16) $4G_H$ **Γ**=
3.76469e-05
Units: kg/person

(17) $4G_H$-S / Y=
pV*$4G_H$ **Γ**
Units: kg

(18) $6G_H$-S / Y=
pV*$6G_H$-S **Γ**
Units: kg

(19) $8G_H$-S / Y=
pV*$8G_H$-S **Γ**
Units: kg

(20) $4G_H$-S=
$4G_H$-S / Y
Units: kg

(21) $6G_H$-S **Γ**=
8.97953e-05
Units: kg/person

(22) $6G_H$-S=
$6G_H$-S / Y
Units: kg

(23) $8G_H$-S **Γ**=
2.14309e-06
Units: kg/person

(24) $8G_H$-S=
$8G_H$-S / Y
Units: kg

(25) *A*=*A* **Γ***P_P
Units: person

(26) *A* **Γ**=
0.016628
Units: Dmnl

(27) -Chemical waste=
Tissue G_H-S/ Y+$3G_C$-F / Y+ER_C F / Y+$3G_C$-S / Y+ UG-S / Y+2G-S / Y+$4G_H$-S / Y+$6G_H$-S / Y +Gynecology $_H$ S / Y+wings $_H$ S / Y+MICU $_H$ S / Y +8 G_H-S / Y+$3G_H$-S / Y
Units: kg

(28) *∂*= *∂* **Γ*** P_P
Units: person

(29) *∂* **Γ**=
0.0035
Units: Dmnl

(30) ER_C F / Y=
pV*ER F-C **Γ**
Units: kg

(31) ER_C F=
ER-C F / Y
Units: kg

(32) ER_C F **Γ**=
2.67171e-05
Units: kg/person

(33) FINAL TIME = 30
Units: Year
The final time for the simulation.

(34) Gynecology $_H$ S=
Gynecology $_H$ S / Y
Units: kg

(35) Gynecology $_H$ S / Y=
Gynecology $_H$ S **Γ*****p***V
Units: kg

(36) Gynecology $_H$ S **Γ**=
3.71468e-06
Units: kg/person

(37) INITIAL TIME = 0

Units: Year
The initial time for the simulation.

(38) $MICU_H$ S=
$MICU_H$ S / Y
Units: kg

(39) $MICU_H$ S / Y=
$MICU_H$S **Γ***$\boldsymbol{p}$*V
Units: kg

(40) $MICU_H$ S **Γ**=
9.50102e-06
Units: kg/person

(41) ***p***V=
$p_{\mathcal{P}}$ *0.0679539
Units: person

(42) $p_{\mathcal{P}}$ = INTEG (-∂, 1.03e+07)
Units: person

(43) SAVEPER =
TIME STEP
Units: Year
The frequency with which output is stored.

(44) TIME STEP = 1
Units: Year
The time step for the simulation.

(45) tissue G_C F **Γ**=
0.00225046
Units: kg/person

(46) tissue G_H-S / Y=
pV*tissue-C F **Γ**
Units: kg

(47) tissues-G_C F=
tissue G_H-S / Y
Units: kg

(48) wings $_H$ S=
wings H S / Y
Units: kg

(49) wings $_H$ S / Y=
pV*wings $_H$ S **Γ**
Units: kg

(50) wings $_H$ S **Γ**=
5.85777e-06
Units: kg/person

Ground/Floor	G
Formalin	F
Patient volume	p_V
Rate	**Γ**
Clinics	C
Hospital	H
Patients Population	$p_{\mathcal{P}}$
Arrival	A
departure	∂
Solid	S
Per year	/Y
Underground	U

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Green Taxes and their Impact on Romanian's Economy compared to Investments for Air and Climate Protection

By Carmelia Mariana Bălănică Dragomir[*]*, Cornelia Marin*[±] *& Cristina Garlea*[°]

Climate changes are more and more evident and their effect is increasingly extensive, and in the current context the environmental taxes may become a key factor in ensuring the sustainable development for the entire society. This article presents a medium-term analysis of the main categories of environmental taxes, their evolution compared to the investments for air and climate protection, as a percentage of GDP, made in Romania. Four main categories of environmental taxes: energy taxes (including transport fuels); transport taxes (excluding transport fuels); pollution taxes and resource taxes are collected in Romania, yearly. The data used in this study provides from the National Institute of Statistics. During 2006-2020, in Romania the highest percentage is represented by energy taxes 88%, in second place are taxes for transports 10% and in the third and fourth places with insignificant percentages (about 1%) are the taxes for resources and for pollution. From the four categories of environmental taxes, it can be seen that resource taxes have a decreasing trend from 51.6 million euros in 2006 to 3.84 million euros in 2020, while energy taxes, transport taxes and pollution taxes have an increasing trend.

Keywords: *climate changes, environmental taxes, sustainable development, air and climate protection*

Introduction

Climate change and the resulting impacts have become a priority and at the same time a widespread concern in the international society, being among the major challenges of the actual century (He et al. 2023). The damage cost of global warming will expand considerably quicker than global economic output, and carbon dioxide (CO_2) is the primary origin of climate crisis and greenhouses warming (Gunawardene et al. 2022). Carbon dioxide is connected to atmospheric warming within the phenomenon well-known as the climate change and the concentration of CO_2 in the environment is a fundamental impact on Earth's climate (Müller et al. 2018).

In accordance with the general average statistics of the Earth system model, the meteorological condition will obviously change in the 21st century and the temperature is estimated to increase by among 1.0 and 3.7 °C on the basis of forthcoming carbon dioxide footprint (Khandekar et al. 2005, Anderson et al. 2016). For fulfilment the Paris Agreement 2015 objectives that target of restricting

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the average greenhouses warming less than 2.0 ˚C referring to pre-industrial status, it is crucial to accomplish strict mitigation policies to minimize human-caused CO_2 emissions to substantially reduce the cost-effective effect of global warming (Qiang et al. 2020). The rise in the earth's atmospheric temperatures caused by climate warming impacts the entire planet, having also an essential influence on the durability and evolution of all species, and is furthermore a main challenge to the complete ecological system (Oktyabrskiy 2016). The issue of global warming generated by GHG (Greenhouse Gas) emissions has already exceeding nationwide frontiers. Therefore, it is not compulsory to reach the emission diminution goals of distinct states, but much more significantly to manage the complete worldwide CO_2 emissions. Global collaboration has an absolute function in encouraging emission decreasing (Koseoglu et al. 2022). It is essential to aim for an international partnership to manage climate variability (Youssef et al. 2023) and to establish a series of commonly approved rules of lead that can be applied between various countries. Considering the development of industrial sector, unsustainable energy usage and production prototypes linked with increase of population and socio-economic progress are some of the principal driving factors behind the raise in anthropogenic CO_2 emissions (Demiralet al. 2022).

This article has the next research motivations: to study the green taxes trend between 2006-2020 in Romania, depending on the type of taxes: energy taxes (including transport fuels), transport taxes (excluding transport fuels), pollution taxes, resource taxes. Concomitant at the same time, we will analyze the trend of investments and expenses in the field of air pollution and climate change. Beginning with the half of the nineteenth century, climate change has been the extreme obvious, resulting unusual global variation and these determine more frequent extreme weather incidents.

Literature Review

Environmental taxes have a fundamental function in impacting polluting economically activities throughout the cost mechanism, being an economic tool used complete for sustainable progress that stipulates innovative concepts for confronting global warming (Heine et al. 2019). From one perspective, states are able to establish norms for the management of carbon-dioxide emissions based on the principle of ”polluter pays” and considering their effective circumstances, hence that ecological taxes should turn into a globally relevant but individualized approach of greenhouse gas reduction and carbon neutrality. On the contrary, environmentally related taxes are a category of stimulative direction (Costantino et al. 2023), whereas the concept of specific resources provides particular economic capital for ecogovernmentality, environmental policy act and climate action, although several advantageous fiscal policy-making are contributory to heartening undertakings to take up pollution control technology and eco-friendly equipment. Mensah et al. (2019) mentioned that the insertion of ecological taxes is able to minimize emissions of greenhouse gas, particularly CO_2 emissions. Collecting environment related taxes has turn into an innovative plan for the worldwide society to manage with global warming and lessen the periodicity of extreme weather events.

The 38 member countries of the Organization for Economic Co-operation and Development (OECD) countries have developed the take of the advantage of environmental taxes, that are extensively considered as providing compensations for durable efficient progress, investment in eco-friendly technology and amendments in consuming models. Global warming taxes is having an essential task in the agri-environmental actions of the European community (Rafique et al. 2022). Starting with 1972 OECD states proposed the principle of ”polluter pays”, obliging all those who pollute needs to support the expenses of releasing contaminants in order to achieve internalization of external charges. Only after the 1990s, OECD states have started to accomplish environmental taxes reform, that intends to achieve the transition from taxes to green taxes whereas adjusting ecological externalities and diminishing distorting fiscal consequences regarding different markets (Eyraud et al. 2013).

Currently the green taxes charged by these states consist in emissions taxes, fuels taxes, auto traffic taxes, polluting taxes, production taxes and different taxes aimed to monitor pollution and their impact. Environmental management taxes have change into the principal instrument of green strategies in numerous OECD members. Overall, the evolution of environmental taxes in OECD states, the basic strategy orientation of green taxes is to limit and regulate emissions and subsequently achieve environmental preservation. Nevertheless, gradually, the effect of global warming on the economy sector is higher compared to atmospheric pollution. It is expected that by 2060, the financial damage attributable to global warming will be approximately 3% of gross domestic product, and the economic impact chargeable to pollution of the atmosphere will be for around 1% (OECD 2019). Decreasing of environmental pollution and reaction to global warming are the two target to accomplish economic sustainability of current society. Linking global warming reduction and atmospheric pollution monitor strategies may create substantial interactions hence the advantages of combined policy activities supposed to be additional targets in an exhaustive mode. Moreover, taking into account the fact that carbon dioxide (CO_2) is included in the category of the principal elements impacting the pollution of the air and climate variability, the basic source for ecological conservation and pollution control and of green taxes, particularly for CO_2 as the standard for an emission charges, to a major extent should be supposed to be the essential steps in connecting with global climate change.

By combining two important targets: global warming mitigation and adaptation and air pollution control may obtain considerable interactions and not simply supports to touch into the immense capabilities of current national environmental standard in reviewing climate variability and extreme weather phenomena, apart from extends study viewpoints and complete the actual publications. The link among global warning strategies and pollution of the air is extensively accepted. It is universally established that exhaustive study of climatic variations and atmospheric pollution is required, therefore a substantial percentage of papers have considered quantifiable the common advantages of climate strategy on atmospheric environment (Aminzadegan et al. 2022). It may be considered that there is a close connection among climate change and pollution of the environment, whereas the actual research barely studies the function of environmental pollution strategies in mitigating climate change and diminishing severe weather incidents. Since an extensively used environmental pollution manage approach in OECD countries, the issue of green taxes has had a position in confronting climate variability in a prolonged interval of time may be determined by using the large-scale calculations and experimental test at this phase (Smith et al. 2017).

Emission decreasing stimulants cannot merely restrict the circumstances of energy production or consumption activities and at once lessen pollutant emissions, but also support the growth of environmental protection technologies settled on the emission diminution and high-tech progress in the domain of environmental protection. Parry (2012) suggested the idea of restricting greenhouse gas emissions in the group of taxes to mitigate pollution, and based upon Bouwer (2013), suggested the theory of absorption of the external cost of pollution of the environment.

Taxes transfer allows the green taxes is not only the target to bear environmental benefits green profit, but may lower the current taxes system to the constituents of production similar to capital, labor and additional promote assignments and support economic development and provide all the consequence (Dogan et al. 2023).

This article presents an analysis of the evolution of the collection of environmental taxes on the four categories: energy taxes, resource taxes, transport taxes and pollution taxes. All the data used in this study come from the National Institute of Statistics in Romania.

In order to analyze a comparison between the taxes collected in the period 2006-2020, we used the data on investments for air and climate protection, as a percentage of GDP and expenditures for air and climate protection as a percentage of GDP, having the same source, the National Institute of Statistics from Romania.

Materials and Methods

Green taxes originate from the tax system utilized in public accounting and consist in compulsory expenditures that are collected through public governments or European Union bodies. Environmental taxes represent an important instrument of environmental policy, which is included in the category of economic instruments for environmental protection, pollution control and natural resource management.

In compliance with the standards of economic sustainability and the target to accomplish an efficient utilization of natural resources and non-polluting economy, respecting the Europe policy and in multiple principal schemes, the elaboration of a data framework that consistently contains environmental elements in addition to economic ones it becomes altogether the more indispensable. In order to transpose European legislation, the legislative framework for collecting data on environmental accounts was created in Romania, namely Regulation (EU) no. 691/ 2011 of the European Parliament and of the Council of July 6, 2011 regarding European environmental economic accounts and Regulation no. 538/2014 amending Regulation (EU) no. 691/2011 on European environmental economic accounts.

Environmentally related taxes statistics register and provide data from the perspective of tax-paying entities in a method that is perfectly compatible with data stated in national accounts. In this case are registered the income related to the environmental taxes of the state economies according on the economic sectors. Manufacture and consumption are included as economic activities. Environmental taxes deduce from the fiscal policy used in national accounting and are consist in mandatory payments, without consideration, in cash or in kind, which are collected by public administrations or European Union institutions.

The time series of revenues on each environmental tax and on the four main categories of environmental taxes: energy, transport, pollution and resource taxes are included in the standard forms, which meet the reporting requirements of Regulation (EU) no. 691/2011 of the European Parliament and of the Council of July 6, 2011 regarding European environmental economic accounts.

In accordance with the Environmental Taxes Account (RNIS 2021), the main purpose of environmental taxes is to aim to integrate the cost of the negative impact on the environment into prices. In this way, consumers and producers must use resources responsibly natural and limit or avoid pressure on the environment.

The principal potential advantages of taxes consist in the provision of income for local and central authorities. The revenue generated by environmental taxes can be used for other environmental conservation projects or to reduce other taxes.

As stated in the Eurostat methodological guide (2013) there are four main groups of environmental taxes: energy taxes (including transport fuels); transport taxes (excepting transport fuels); pollution taxes; resource taxes.

Energy taxes involve taxes on energy products used both for transport and for energy and industrial processes. The most significant products energy for transport consists in petrol and diesel. Included the category of energy products energy and industrial processes are take into account: fuel oil, natural gas, coal and electricity. Meanwhile, CO_2 and SO_2 taxes are included in this category because they are complicated to distinguish independently in fiscal statistics.

If we analyze in detail, this category includes: energy products for transport: unleaded petrol, leaded petrol, diesel, other energy products for transport purposes (for example LPG or natural gas); energy products for stations: light fuel oil, fuel oil, natural gas, coal, coke, biofuels, production and consumption of electricity, production and consumption of district heat, other energy products for stationary use; greenhouse gases: carbon content of fuel, greenhouse gas emissions (including revenues from emission permits recorded as taxes in the national accounts).

Transport taxes predominantly contain property and use taxes vehicles. Taxes on different transport equipment (e.g., aircraft) and connected services of transport, like tax on charter or scheduled flights, are additionally included in this category, if they conform to the general description of environmental taxes. Shipping charges may be taxes with reference to imports or sales of motor vehicles or constant outgoings such as tax on annual road. Taxes on the consumption of gasoline, diesel and other fuels used for shipping are not included in shipping charges. Transport taxes include: transport (excluding transport fuels), import or sale of motor vehicles, registration or use of motor vehicles, recurring (e.g., annual charges), road use (e.g., motorway charges), congestion charges and city taxes (if the taxes enter the national accounts), other means of transport (ships, planes, trains, etc.), air transport and plane tickets and vehicle insurance (excludes general insurance taxes).

Pollution taxes are applied to emissions from mobile and immovable sources, when some are sold goods (batteries, dangerous chemicals, tires, plastic bags, plastic packaging and cardboard). Therefore, they are the taxes that apply to air and water emissions, solid waste and noise. In this category does not include CO_2 taxes, as they were included in the tax category on energy.

Environmental taxes consist of the following air emissions - measured or estimated: NOx emissions - measured or estimated, SOx emissions - measured or estimated, other air emissions - measured or estimated (except CO_2), substances that diminish the ozone layer (e.g., CFCs and halons); effluents in water - measured or estimated, effluents of oxidizable matter - measured or estimated (BOD, COD), other effluents in water measured or estimated, treatment and collection of effluents, fixed annual fees; non-point sources of water pollution, pesticides (based for example on chemical content, price or volume); chemical fertilizers (e.g., based on phosphorus or nitrogen or nitrogen content), manure, waste management, collection, treatment or storage, individual products (e.g., packaging, beverage containers, batteries, tyres, lubricants); noise (e.g., airplanes taking off and landing).

Resource taxes are taxes that apply to the exploitation of natural resources (water, minerals, wood, etc.), other than those used as energy sources. However, there are differences of opinion whether the extraction of natural resources is, in itself, harmful or not, although there is an agreement generally that this can lead to environmental problems such as soil erosion and pollution. The main sources of resource taxes are: water abstraction, exploitation of biological resources (e.g., timber, game and fish species), extraction of raw materials (e.g., minerals, oil and natural gas) and landscape modification, tree cutting.

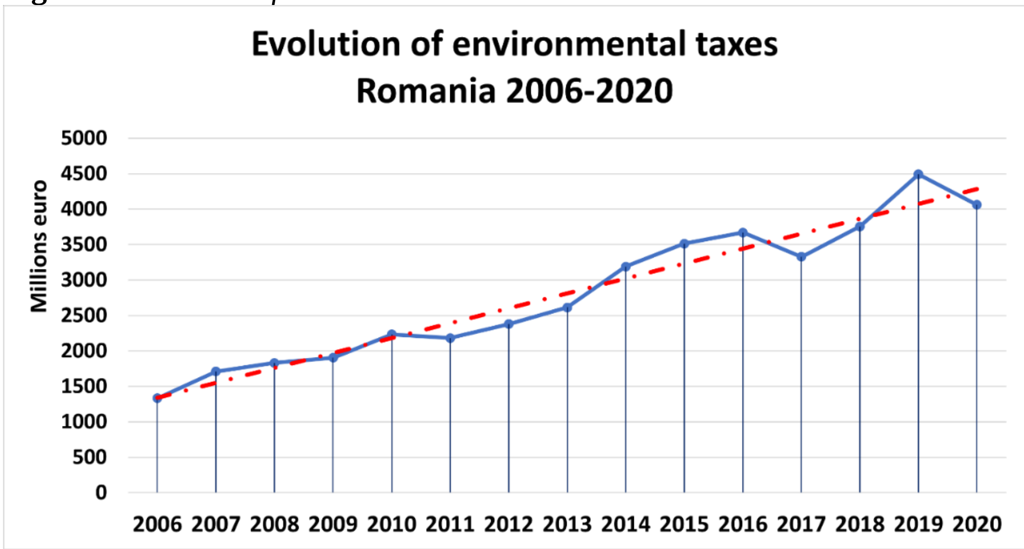
Expenditures for environmental protection are the basis of the concept of sustainable development, promote the continuity of economic and social development without causing damage to the environment and natural resources essential for human activity. According to the Romanian National Institute of Statistics, Expenditures for air and climate protection as a percentage of GDP, obtaining data on environmental protection expenses is an integrative activity of the requirements of statistical representation of environmental protection and the interests of enterprises in the evaluation of their own environmental performance. Although the evaluation of the environment and the effects of environmental policies is difficult, the use of data on environmental protection expenditures can guide the general management of the unit by providing some indications on the environmental benefits resulting from a combined economic-environmental policy. These categories of information are obtained from the public administration and from the productive sector "enterprises" (RNIS 2022a).

Based on Romanian National Institute of Statistics, Investments for air and climate protection, as a percentage of GDP, investments for environmental protection include all capital expenditures related to environmental protection (involving methods, processes, technologies, equipment or parts thereof) the primary purpose of which is to collect, treat, monitor and control, reduce, prevent or eliminate pollutants or pollution or other environmental degradations, resulting from the operative activity of the units. The total investment consists of the sum of the investments necessary to reduce the emissions of polluting substances resulting from the production process and the treatment of pollution called environmental protection at the end of the production process and the prevention of pollution called environmental protection integrated in the production process (RNIS 2022b).

Results

For the purpose of observe the evolution of environmental taxes in Romania, between 2006 and 2020 we analyzed the dataset collected by National Institute of Statistics, collected according to the European legislation. The total value of these taxes in the analyzed period was 38,125 million euro.

Figure 1. *Evolution of Environmental Taxes in Romania 2006-2020*

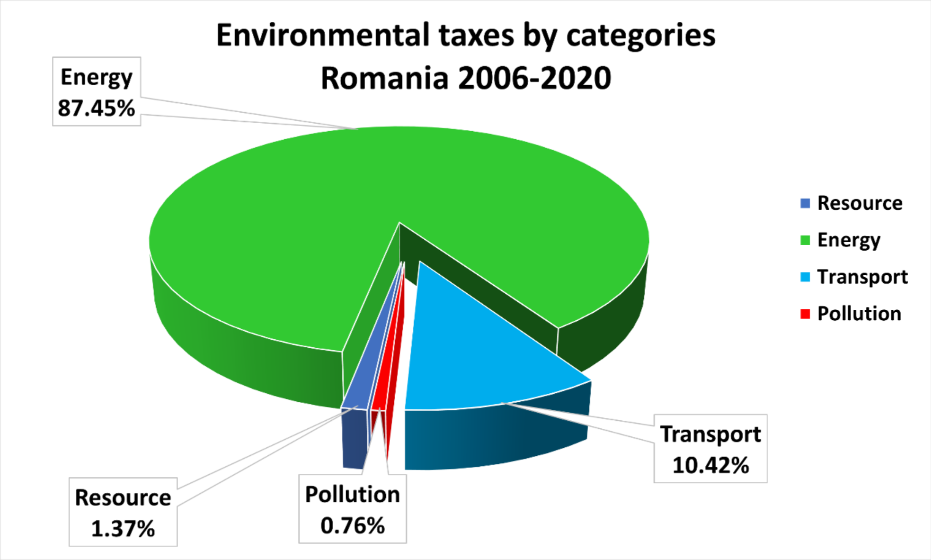


The upward trend is one that can be clearly seen from the data analysis. If in 2006 the value of environmental taxes, in total, was 1,331 million euro, this value almost tripled in 2020, reaching 4,059 million euro. The highest value is that of 2019 of 4,490 million euros, but overall, these values have constantly increased by 10-20% annually. It should be mentioned that even when Romania went through a period of economic crisis between 2009-2011, these taxes continued to increase.

Comparable to the other member countries of the European Union, in Romania environmental taxes are composed of four categories of taxes, namely: resource taxes, energy taxes, transport taxes and pollution taxes.

The highest percentage of 87.45% is provided from energy taxes which includes any tax existing on fuels, energy generation, transmission, or consumption. At the same time, CO_2 and SO_2 taxes are also included in this category because they are difficult to identify separately in tax statistics. The main purpose of these taxes is to facilitate the clean energy transition towards a series of less polluting investments. On second place, but at a very long distance, are the taxes for transport, in a percentage of 10.42%. From this category, the most significant part results from motor vehicles import or sale, road use or other means of transport (naval, air and railroads transport, etc.).

Figure 2. *Environmental Taxes by Categories in Romania 2006-2020*



Taxes on resources are in third place in this analysis with a percentage of only 1.37%. These taxes consist of the extraction of raw materials: minerals, oil and gas, water abstraction, timber extraction, etc. Pollution taxes represent the lowest percentage of only 0.76%, and the activities that make up this type of taxes include measured or estimated emissions to air, measured or estimated effluents to water, waste management and noise pollution.

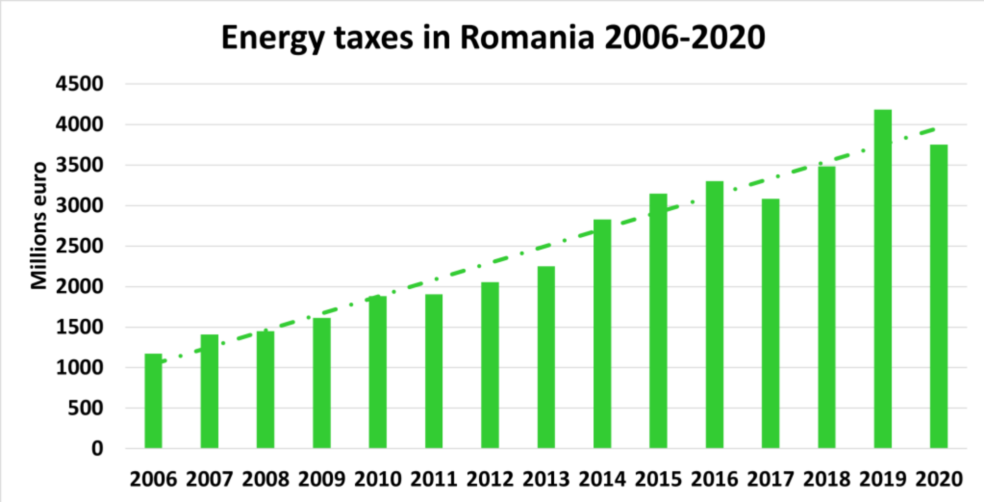
Energy taxes, containing fuel for transport, have evolved gradually, starting from 1,174.50 million euros in 2006 and reaching 3,753.24 million euros in 2020, which represents an increase of approximately 69%, in a period of 15 years.

In 2014 there is an increase to 2,829.69 million euro compared to 2,252.46 the previous year, 2013, and in 2019 a threshold of 4,184.34 million euro is reached, being the highest value recorded in the studied period.

The principal energy products for transport are equally petrol and diesel, including at the same time the energy products for stationary utilization consisting in petroleum distillates, gasoline, coal and electrical energy. Taxes on biogases and on different types of energy resulting from renewable sources are also contained in this category, but mostly are included taxes on storage of energy products.

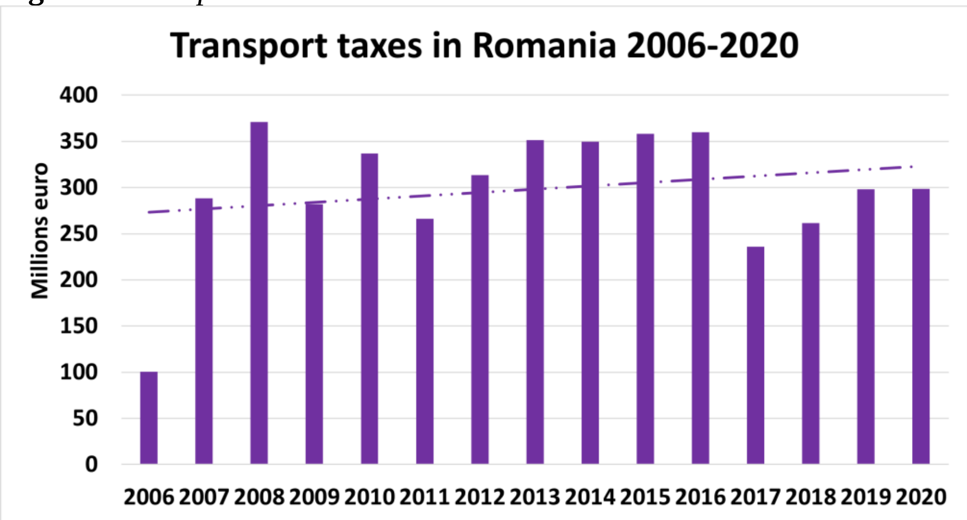
The most important aspect is the inclusion of CO_2 in the category of energy taxes due to the fact that this pollutant cannot be identified separately in the collection of energy taxes, it being integrated in the differentiation of mineral oil tax rates in accordance with the carbon content of the fuel.

Figure 3. *Energy taxes in Romania 2006-2020*



The second category of taxes, transport taxes, includes all types of taxes arising from the ownership and use of a motor vehicle. Environmental taxes resulting from related transport services regardless of the type of regular or charter flight are part of the category of transport taxes, containing at the same time taxes on other transport equipment, for example, planes, ships or railway wagons. Transport taxes also have an upward trend starting from 100.5 million euro in 2006 and reaching 298.42 million euro in 2020, the growth percentage being 66%.

Figure 4. *Transport Taxes in Romania 2006-2020*



The most sudden increase in transport taxes is the one in 2006 compared to 2007 when it increased by 188 million euros, the rise continuing in 2008 with 82 million euros more. Between 2013 and 2016, transport taxes remained relatively constant at around 350 million euro.

All taxes on public transport should be included, regardless of whether we take into account the category of transport that are considered to be in some measure more nonpolluting similar to railways and trams or trolleybuses.

The only category of taxes that has a decreasing trend is that of taxes on resources, starting from 51.6 million euros in 2006 and reaching only 3.2 million euros in 2020. If we compare the taxes from 2006 and 2007, we can observe that the tax from 2007 is only 20% compared to the one from the previous year.

Figure 5. *Resource Taxes in Romania 2006-2020*

For the entire period 2006-2020, the entire amount collected as part of the resources category is 128 million euros, of which 40% were collected in the first year.

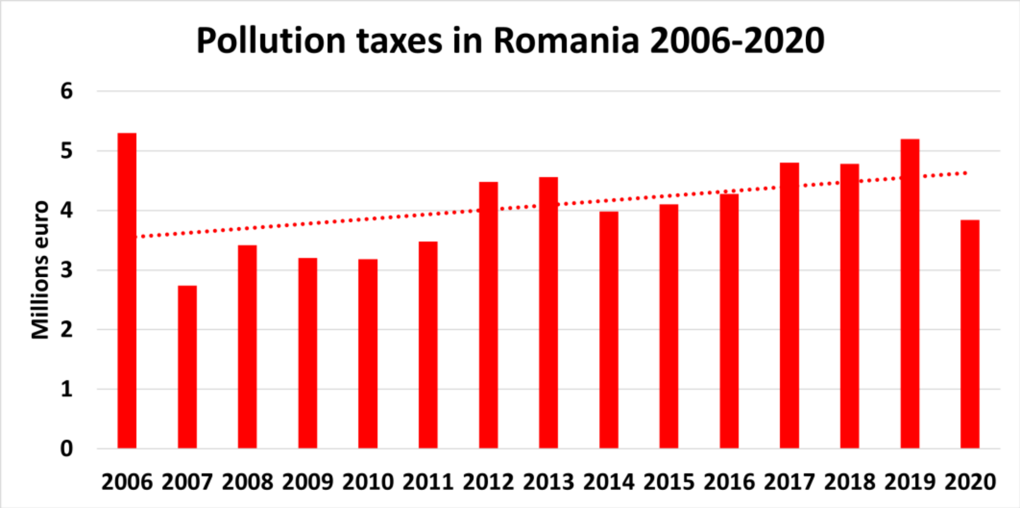
From the category of resource taxes are included several taxes connected to the extraction or to the utilization of natural resources, like as water, woodlands, biodiversity and aquatic and terrestrial ecosystems, etc., all types of activities consuming natural resources.

The fourth category of taxes is that of pollution taxes, which as an amount, in the 15 years analyzed, represents only 61.34 million euro. The trend is an increasing one, although the tax from 2006 had a value of 5.3 million euro compared to 2020 when the tax was 3.84 million euro.

From the point of view of the types of taxes included in this category, we must mention taxes on measured or estimated emissions of environmental factors: air water and soil, noise simultaneously with management of solid waste.

All four categories of taxes are based on the "polluter pays" principle, which must have as its final goal shifting tax out of activities as regards pollution, throughout decreasing no sustainable contributions.

Figure 6. *Pollution Taxes in Romania 2006-2020*

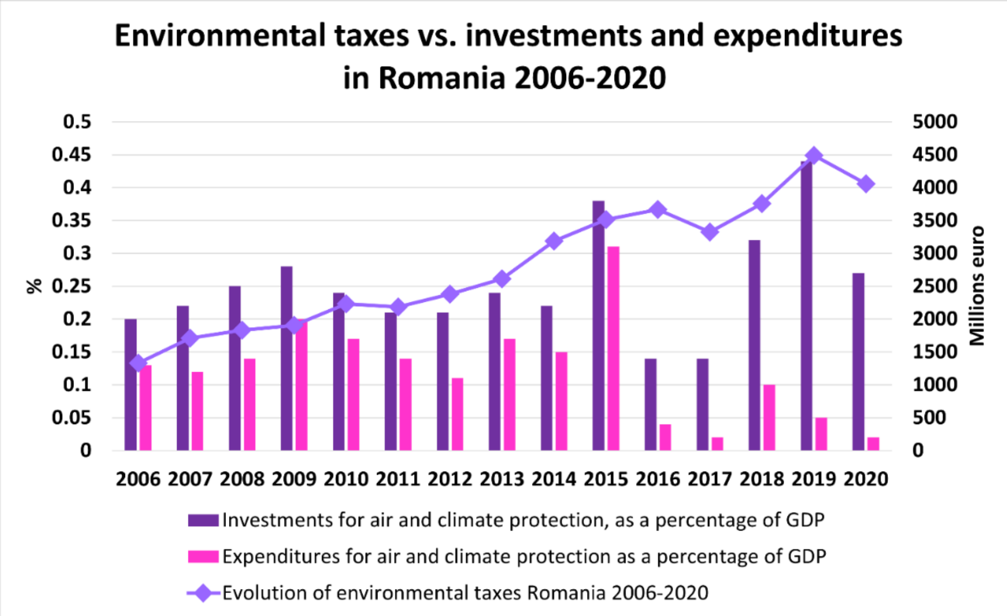


The fundamental target of any carbon pricing strategy is to mitigate carbon emissions, indicating that, if efficacious, the usage of fossil energy will lessen over the years. Although this furthermore means that profits from current or newly introduced fuel taxes and carbon costing policies will diminish as a consequences of the depreciation of the tax base as the guidelines perform successfully. It is thus the general net impact that is appropriate for any consequential research.

In Romania, during 2006-2020 average taxes were collected in the amount of 39.143 million euro. Unfortunately, at the level of official statistical data, we could not find the amounts used for investments and expenses for environmental protection except in the form of a percentage of GDP, which makes it very difficult to compare the amounts received with those spent to reduce pollution and climate change. Figure 7 shows investments and expenditures for air and climate protection, as a percentage of GDP in comparison with taxes collected in the same period. On the right axis are represented in the form of a line the taxes in millions of euros and on the left axis in percentage of GDP, in the form of columns are the investments and expenses.

During the entire analyzed period, 15 years, the investments were higher than the expenses, which indicates that the new investments focus on the use of non-polluting and environmentally friendly equipment. The highest differences between investments and expenses are those of 2019 and 2020 with variations of 0.39% of GDP and 0.25% of GDP, respectively. Between 2010-2015, the difference of 0.7% of GDP between investments and expenditures was maintained almost constantly. From the visual analysis, it can be seen that the trend of taxes and expenses and investments are similar and obviously follow the same directions. The most obvious similarities are those of the years 2015 and 2019, when both expenses and investments for air and climate protection, as a percentage of GDP, as well as the four tax categories had similar increases, but also the years 2017 and 2020, when there were the same decreases.

Figure 7. *Environmental Taxes vs. Investments and Expenditures in Romania 2006-2020*



For a more accurate analysis of the similarities between the two categories of analyzed factors, we calculated the Pearson correlation coefficient, just to clearly see if there is a degree of interdependence or not. SPSS IBM 27 software was used to calculate the Pearson correlation coefficient, using the three variables: investments for air and climate protection, as a percentage of GDP, expenditures for air and climate protection as a percentage of GDP and evolution of environmental taxes Romania 2006-2020. Table 1 shows the Pearson correlation coefficients for the three variables, for a period of 15 years.

Table 1. *The Pearson Correlation Coefficients for the Three Variables, for a Period of 15 Years, 2006-2020*

		Investments for air and climate protection, as a percentage of GDP	**Expenditures for air and climate protection as a percentage of GDP**	**Environmental taxes Romania 2006-2020**
Environmental taxes Romania 2006-2020	Pearson Correlation	**0.430**	**-0.381**	1
	Sig. (2-tailed)	0.109	0.162	
	N	15	15	15
Investments for air and climate protection, as a percentage of GDP	Pearson Correlation	1	0.319	0.430
	Sig. (2-tailed)		0.247	0.109
	N	15	15	15
Expenditures for air and climate protection as a percentage of GDP	Pearson Correlation	0.319	1	-0.381
	Sig. (2-tailed)	0.247		0.162
	N	15	15	15

From the statistical analysis, it is obvious that there is an average positive correlation between environmental taxes Romania 2006-2020 and investments for air and climate protection, as a percentage of GDP, with a coefficient of 0.430. An average negative correlation between environmental taxes Romania 2006-2020 and expenditures for air and climate protection, as a percentage of GDP, with a coefficient of -0.381.

Discussion

It is indubitably time for environment-related taxes and carbon pricing strategies to come to the fore, and their significance and consequence may be anticipated to obtain larger distinction in the course of the switch to a climate-neutral economy. Moreover, they are partially included as an alternative for different energy taxes and the income from these taxes may be very significant compared to the revenue from eco-taxes.

This indicates that combining carbon emissions taxes with pollution taxes as opposed to energy taxes would distort equally the time series at national rank and international similarities. If carbon emissions taxes are distinguishable, these taxes supposed to be stated as a distinct category adjacent to the total energy taxes. Taxes on greenhouse gases emissions other than carbon dioxide ought also to be inserted here.

Conclusions

Energy taxes vary from 1174.5 million euros to 3753.2 million euros, transport taxes almost tripled in the analyzed period from 100.5 million euros to 298.42 million euros and pollution taxes had a value of 5.3 million euros in 2006, 5.2 million euros in 2019 and only in 2020 this tax was 3.84 million euros.

In accordance with the impositions of the European Union, in Romania, in the period 2006-2020, the following categories of taxes were collected: resource taxes worth around 124.2 million euro, energy taxes in the amount of 33770.43 million euro, transport taxes in the amount of 4173.4 million euro and pollution taxes of approx. 57.5 million euro. As the highest collected fees are observed are the ones energy taxes and the lowest fees collected are the ones are pollution taxes.

From the statistical analysis of the Pearson correlation coefficient, it emerged that during the 15 years there is an average interdependence between investments for air and climate protection, as a percentage of GDP, expenditures for air and climate protection as a percentage of GDP and environmental taxes from Romania 2006-2020.

The impact system of environmental taxes may be explained as follows: first of all, the tax on environmental protection promoted the control of pollution by modifying the outward costs of pollution within the internal costs for companies. Secondly, by promoting green design, the regulatory agencies should monitor their air pollutants emissions in a certain area. As the third statement, the tax policy encouraged the progress of environmental protection capabilities in the urban zone, which in turn restrained the pollutant emissions in the metropolitan areas.

Generally, this study provides a conceptual basis for the common efforts of local authorities to reduce pollution besides the suggestions to facilitate the transfer from individual to multi-stakeholder partnership.

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Cleft Grafting Propagation of Pome and Stone Fruit Trees during the Dormancy Period in a Hot Water System

By Stefan Gandev, Plamen Ivanov±, Angel Dimitrov° & Penka Filyova•*

Pome and stone fruit trees are heterozygous and cannot be propagated by seed. Various techniques are used for their vegetative propagation worldwide. The experiment's results are noteworthy, especially in the realm of fruit tree propagation. By utilizing a heated callus with a hot water system, combined with the cleft grafting method, successful propagation of both pome and stone fruit species has been accomplished. The experiment's results were intriguing, revealing varying success rates among different fruit species. The apple, pear, and plum fruit species achieved a higher percentage of callus-forming, adapted, and fruit-planting material compared to the sweet cherry. The highest success rate was observed in apples – 83.1%, followed by pears – 67.5% and plums 63.8%. The sweet cherry, a stone fruit species, had the lowest success rate at 20.6%. These findings open up new avenues for further research and experimentation. The use of a hot water system during the winter dormancy of apple, pear, and plum species has proven to be a successful propagation method. Therefore, we confidently recommend this method for these species, as it can greatly enhance fruit tree propagation practices. This recommendation is based on the solid results and advancements achieved in our experiment.

Keywords: *fruit tree, hot callus, grafting, planting material, cleft technique*

Introduction

The fruit species of apple, pear, plum, and cherry are heterozygous, meaning they have two different alleles of a particular gene. This genetic characteristic of these fruits means that their seed propagation does not lead to the inheritance of the qualities of the selected variety (Lichev et al. 2020). For this reason, micropropagation, budding, and grafting are widely used as methods of vegetative propagation of the above fruit species worldwide.

Micropropagation is used for the rapid vegetative propagation of plants under sterile conditions, genetically identical to the mother ones (Morini, 2019). Successful micropropagation of apple, pear, plum, and sweat cherry species has been reported in the literature (Thakur et al. 2008, Dobránszki et al. 2010, Hartmann et al. 2011, Clapa et al. 2013). The propagating material produced from the fruit mentioned above crops, obtained by micropropagation of the varieties, is not preferred by fruit growers when establishing an orchard. This is because the

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micropropagated varieties have their roots, i.e., the produced trees do not have the advantages that vegetative rootstocks provide. However, micropropagation of cultivars is mainly used to create an in vitro genetic bank to support and preserve the relevant genotypes.

In recent decades, a significantly new grafting technique has emerged, the so-called micrografting. This *in vitro* grafting technique involves the placement of a meristem or shoots tip-explant onto a decapitated rootstock grown aseptically from seed or micropropagated cultures (Hartmann et al. 2011). The method holds great potential for improvement and large-scale multiplication of fruit plants. It has been used commercially to produce virus-free plants in fruit crops and viroid-free plants in Citrus. Micrografting has also been used to predict incompatibility between the grafting partners, histological studies, disease indexing, production of disease-free plants particularly resistant to soil-borne pathogens, and multiplication of difficult-to-root plants (Hussain et al. 2014).

Budding and grafting are the most widely used techniques to propagate multiple tree fruit crops. Grafting on specific rootstocks can provide several advantages: precocity, tree quality, high yields, resistance to diseases and pests, and others. These advantages are due to [specific reasons]. Budding is carried out during the growing season, and grafting is during the winter dormancy of plants (Lichev et al. 2020). Winter grafting is mainly applied to apples (Sumrah et al. 2002) and walnuts (Gandev 2007) and vegetatively to stone fruit species plums and cherries (Lichev et al. 2020). Caruso (2019) reports that grafting during winter dormancy is not a promising propagation method in all stone fruit species, including plums and sweet cherries.

The study aimed to investigate the possibility of propagating the following fruit species: apple, pear, plum, and sweet cherries in a hot water system during winter dormancy.

According to a 2017 study by Gandev, walnut plants can be effectively reproduced during their winter dormancy phase using a water-heating installation. However, it remains unclear if this method can be applied to other fruit species. As such, the current study aims to explore the feasibility of the "hot callus" grafting method, which was first introduced in North America by Lagerstedt in 1981. This method has demonstrated success in nut crops, vineyards, and forest species, as reported by Carey et al. in 2013, Gandev in 2016 and 2017, Gandev et al. in 2019, and Rovira in 2021.

Literature Review

In a separate study, Jitendra et al. found an 82% success rate in scion grafting under polyethylene greenhouse conditions when conducted on February 15. Similarly, Karamursel and Kalyoncu noted that grafting apple plants on rootstock liners during winter dormancy in a greenhouse had a higher success rate (82%) compared to grafting on buds in summer outdoors (69%). They also observed that grafting during the winter dormancy period had the advantage of a lower workload.

Dimitrov et al. (2022a) found that the successfully callus-forming plants of the fruit species of pear (*Pyrus communis* L.) during winter dormancy, respectively, by the method of "stratification" was 83.0% and by the method of "hot callus" in a water heating installation – 83.4%, relatively high rates of reproduction of the fruit species. In other research, Dimitrov et al. (2022b) noticed that in the fruit species apple (*Malus domestica* Borkh.), the percentage of successfully propagated plants was relatively high, from 75% to 97.5%. In the considered variants of the used grafting techniques (“whip-tongue” and “cleft/v-grafting”), better results are observed in “whip-tongue” due to the better adhesion between the scion and the used rootstock.

Methodology/Materials and Methods

The experiment, conducted from 2019 to 2022 at the Fruit Growing Institute in Plovdiv, Bulgaria, aimed to propagate apple, pear, plum, and sweet cherry in a hot water system during winter dormancy. The prestigious institute's reputation for horticultural research underscores the credibility of the study.

Each fruit species was meticulously represented in a trial, with each trial consisting of 4 replicates. Each replicate was carefully represented by 10 plants, ensuring a robust sample size of 40 plants per trial.

Traits:

1. Propagation of apple (*Malus domestica* Borkh.)
2. Propagation of pear (*Pyrus communis* L.)
3. Propagation of plum (*Prunus domestica* L.)
4. Propagation of sweet cherry (*Prunus avium* L.)

Principles of the Hot Water Installation

A remarkable feat of engineering, the hot water system for grafted plants was constructed indoors and meticulously evaluated for efficiency. The installation is a marvel of compactness, with the circulating hot water maintaining a permanent temperature in the heated tunnels. The distance between the separate tunnels is a mere 1.2 m. The system’s elements, ingeniously designed, include a boiler, a pump, metal tunnels with doors, soil heating pipes placed in the tunnels on perlite, valves, and fasteners.

The water in the boilers is kept at a precise 50°C (± 1°C). The temperature in each tunnel is intricately regulated, depending on the quantity of water flowing through the soil heating pipe placed at the bottom of the tunnel. The valves, crucial in this process, meticulously control the water flow in the tunnels (Gandev 2013), ensuring the perfect conditions for the grafted plants.

Selection of Plant Material (Scion and Rootstock) and Entomological Expertise

In the experiment for scions, "mother" trees were grown in a specially adapted greenhouse covered with an entomological net. Each mother plant was planted in a 90-liter container. The middle part of the one-year-old shoots, 15-20 cm long, 6-9 mm thick with three buds, was selected for scions. For select rootstocks, species produced 'in vitro' and seed rootstocks grown in specially adapted greenhouses for rootstock production were chosen. Both the scions and rootstocks were subjected to monthly entomological monitoring and virological testing and were labeled accordingly. Before grafting the scions and rootstocks, an entomological examination was performed to detect the wintering forms of pests, including aphids, mites, and beetles. Woolly apple aphid *Eriosoma lanigerum* (Hausm.), San José scale *Quadraspidiotus perniciosus* (Comst.) and white peach scale *Pseudaulacaspis pentagona* (Targ.) are three types of aphids included in Directive 2014/98/EU with a 0% acceptance rate, based on EPPO Standard PM 4 - Production of healthy plants for planting.

Grafting

To ensure optimal growth and development, the grafted plants were carefully positioned horizontally across the tunnels, with the graft union precisely placed at the heated point perpendicular to the tunnel's longitudinal axis. The roots of the plants outside the tunnel were covered with wet sand, while the tunnel doors were firmly closed and covered with a plastic folio to minimize moisture evaporation (see Figure 1). In the first ten days of February, when fruit species are in winter dormancy, grafting was performed using the 'Cleft' method. A grafting tapeline was used to fix the graft union. One-year-old rootstocks were used as the base for grafting. Florina was grafted on M.9 rootstock for apple, Packham's Triumph was grafted on OHF 333 rootstock for pear, Stanley was grafted on Myrobalan 29C rootstock for plum, and Kordia was grafted on Mahaleb rootstock for sweet cherry (*Prunus mahaleb* L.). The scions were soaked in water for a day to increase moisture before grafting. The root tips of each rootstock were cut to promote the formation of new lateral rootlets. After grafting, the scion tops were dipped in warm paraffin to prevent water loss.

Figure 1. *Grafted Plants in the Tunnels*

Care of the Grafted Plants

According to research conducted by Hartmann et al. in 2011, the temperature at which winter-grafted plants are placed has a notable impact on callus formation, with varying optimal values for different species. In our experiment, we maintained a temperature of 17°C (± 1°C) at the graft union for apple and pear, 16°C (± 1°C) for plums, and 20°C (± 1°C) for sweet cherry. We provided heat to the grafted plants for four weeks while ensuring that the air temperature in the installation building remained between 10 to 18°C through the use of a convector. The plant roots were regularly wet, and the perlite in the tunnel was moistened as needed to maintain optimal moisture levels at the graft union. Once the callus formation process was complete after four weeks, we turned off the heating system (refer to Figure 2).

Figure 2. *Plants Ready for Adaptation*

Upon the completion of the successful grafting process, the plants were carefully relocated to pots and given ample time to adjust, as evidenced in Figure 2. The rate of callus formation was gauged through a visual method, where thriving plants exhibited apparent callus, complete incision closure, and the emergence of shoots and new roots. To ensure a smooth transition, we utilized a steel-glass greenhouse, keeping the temperature at a constant 15°C (±3°C). The adaptation period, represented in Figure 3, was extended from the planting of the container to the observation and cultivation of the field. After the successful grafting process, the plants were placed in pots and given a month to adjust, as seen in Figure 2. The callus formation rate was determined using a visual method, where positive plants exhibited visible callus, complete incision closure, and physiological developments such as shoots and new roots. To facilitate adaptation, a steel-glass greenhouse was used, maintaining a temperature of around 15°C (±3°C). The adaptation period, depicted in Figure 3, spans from container planting to field observation and cultivation.

Figure 3. *Adapted Plants*

In this phase, the callus undergoes differentiation while the root system becomes functional and the plant's photosynthesis mechanism is established. The progress of the plants in the assigned task was evaluated through visual reports of their success rates both prior to and following adaptation, including the percentage of trees that were successfully propagated. During this stage, the callus that has been formed differentiates, the root function is activated, and the plant's photosynthesis apparatus is developed. The success rate of the plants in the particular task was visually reported both before and after adaptation, along with the percentage of trees that were successfully propagated. After the late spring frosts passed (usually at the end of April.), the plants were moved to a shaded field for further cultivation.

The obtained results were processed by Analysis of variance (ANOVA) statistically according to Duncan's method (Steele and Torie 1980) through the program "R studio" (R Core Team 2020), using the package “rstatix” (Kassambara 2021).

Results and Discussion

Based on the established diagnostic standards and in accordance with Directive 2014/98/EU guidelines, it was determined that grafting of pest-free rootstocks and scions was authorized. Over some time, callus formation was observed in the hot water system. Between the 7th and 15th day post-grafting, a visible (primary) callus was observed to form. By the 25th day, the callus formation had ceased, and the grafting site had completely closed. Activation of the cuttings' buds increased to up to 5 cm, and adventitious root development was observed after the 30th day. After reaching the 35th day, the plants were deemed ready for removal from the tunnels.

Table 1 presents the percentage of successfully callus-forming plants across various fruit species, including apple, pear, plum, and sweet cherry. Notably, the apple species demonstrated the highest success rate, serving as a benchmark for comparison. Over the study period (2019-2022), apple consistently achieved a success rate of 90.0%, with yearly variations ranging from 82.5% to 97.5%. In contrast, the pear species, with an average of 16.2% less than the apple, showed a success rate of 78.0% to 80.0%.

The average percentage of successfully callus-forming plants in stone fruit species was 78.8% in plums and 68.8% in sweet cherries. In individual reporting years, the percentage of successful callus-forming plums varies between 75.0% and 85.0%.

Unfortunately, the sweet cherry species faced the most challenges in callus formation. The average percentage for 2019 - 2022 was 68.8%, with the most significant variation observed in individual experimental years—from 45.0% to 95.0%. The winter propagation of sweet cherries in a system with hot water proved to be a hurdle, leading to a lower percentage of successfully callus-forming plants than the other test species.

Table 1. *Percentage of Successfully Callus-Forming Plants in Apple, Pear, Plum, and Sweet Cherry Fruit Species*

Fruit species	**Year**				**Average**
	2019	**2020**	**2021**	**2022**	
	%	**%**	**%**	**%**	**%**
Apple ‘Florina’ (‘Querina’)/’M.9’	*95.0 a	97.5 a	82.5 a	85.0 a	90.0 a
Pear ‘Packham’s Triumph’/’OHF 333’	80.0 b	70.0 b	70.0 a	75.0 a	73.8 b
Plum ‘Stanley’/’Myrobalan 29C’	75.0 b	80.0 ab	85.0 a	75.0 a	78.8 b
Sweet Cherry ‘Kordia’/’Mahaleb’	67.5 b	95.0 a	67.5 a	45.0 b	68.8 b

* Mean values marked by the same letter are not significantly different according to Duncan's test ($p<0.05$).
* Mean values were compared across fruit species.

The hot water propagation system for apple, pear, plum, and sweet cherry plants was studied to determine the percentage of successfully adapted plants. The results are presented in Table 2.

The study revealed that pome fruit species, such as apple and pear, had the highest percentage of successfully adapted plants, ranging from 89.7% to 97.5% for apples and 85.7% to 96.9% for pears. The average percentage for the 2019 - 2022 period was 92.3% for apples and 91.4% for pears, demonstrating that pome fruit species have excellent adaptive ability.

Plum plants also showed promising results, with a percentage of successfully adapted plants ranging from 74.4% to 82.8%. It is noteworthy that plum's adaptive ability is equal to that of apples and pears.

On the other hand, sweet cherry plants showed the lowest percentage of adapted plants, ranging from 15.8% to 55.5%. Statistical analysis revealed that sweet cherries differ significantly from other fruit species. Winter propagation of sweet cherries in a hot water system had a lower percentage of callus-formed plants (Table 1) and weaker adaptation (Table 2).

Table 2. *Percentage of Successfully Adapted Plants for Apple, Pear, Plum, and Sweet Cherry Fruit Species*

Fruit species	**Year**				**Average**
	2019	**2020**	**2021**	**2022**	
	%	**%**	**%**	**%**	**%**
Apple ‘Florina’ (‘Querina’)/’M.9’	*97.5 a	89.7 a	90.6 a	91.3 a	92.3 a
Pear ‘Packham’s Triumph’/’OHF 333’	96.9 a	85.7 a	92.7 a	90.2 a	91.4 ab
Plum ‘Stanley’/’Myrobalan 29C’	82.8 b	74.4 a	78.6 a	82.8 a	79.6 b
Sweet Cherry ‘Kordia’/’Mahaleb’	55.5 c	15.8 b	19.9 b	40.0 b	32.8 c

*Mean values marked by the same letter are not significantly different according to Duncan's test ($p<0.05$).
*Mean values were compared across fruit species.

In conclusion, this study highlights the effectiveness of hot water propagation for pome fruit species and plum plants. However, it also emphasizes the challenges of propagating sweet cherry plants using this method. These findings can be helpful for farmers and horticulturists in deciding which fruit species to propagate using hot water propagation.

The data from our research is clear and conclusive. There exists a significant difference in the percentage of fruit planting material produced at the end of the vegetation season between different fruit species. According to Table 3, the values for the reporting period are 83.1% for apple, 67.5% for pear, 63.8% for plum, and 20.6% for sweet cherry. It is important to note that sweet cherry produced the lowest percentage of fruit planting material despite variations between 12.5% and 37.5% in different trial years. Our study provides compelling evidence that apples, pears, and plums are superior choices for fruit production compared to sweet cherries. Farmers and growers looking to maximize their yields should consider these findings when selecting fruit species for their orchards. Our research, which is based on reliable data, has shown that there is a significant difference in the percentage of fruit planting material produced at the end of the vegetation season between the following fruit species: apple, pear, plum, and sweet cherry. According to Table 3, the average percentage of fruit planted material produced during the reporting period is as follows: apple – 83.1%, pear – 67.5%, plum – 63.8%, and sweet cherry – 20.6%. It is worth noting that the percentage for sweet cherry varies between 12.5% and 37.5% in different trial years, but the average percentage is still the lowest compared to the other fruit species.

Table 3. *Percentage of Fruit Planting Material Produced for Apple, Pear, Plum, and Sweet Cherry Fruit Species at the End of Vegetation Season*

Fruit species	**Year**				**Average**
	2019	**2020**	**2021**	**2022**	
	%	**%**	**%**	**%**	**%**
Apple ‘Florina’ (‘Querina’)/’M.9’	*92.5 a	87.5 a	75.0 a	77.5 a	83.1 a
Pear ‘Packham’s Triumph’/’OHF 333’	77.5 b	60.0 a	65.0 a	67.5 a	67.5 b
Plum ‘Stanley’/’Myrobalan 29C’	62.5 c	62.5 a	67.5 a	62.5 a	63.8 b
Sweet Cherry ‘Kordia’/’Mahaleb’	37.5 d	15.0 b	12.5 b	17.5 b	20.6 c

* Mean values marked by the same letter are not significantly different according to Duncan's test ($p<0.05$).
* Mean values were compared across fruit species.

Conclusions

A system that incorporates water heating has proven effective in ensuring the successful propagation of apple, pear, and plum fruit species during their winter dormancy.

The average percentage of fruit planted material produced was 83.1% for apples, 67.5% for pear, 63.8% for plum, and 20.6% for sweet cherry.

However, the same method does not yield satisfactory results when attempting to propagate sweet cherry fruit species. The percentage of callus-formed, adapted, and produced trees could be much higher in such cases. Therefore, it is not recommended to use this method for propagating sweet cherry fruit species.

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How to Teach Literacy to Artificial Neural Networks Making AI intelligent by Learning from other Disciplines

By Thomas Fehlmann[*] & Eberhard Kranich[±]

What does literacy mean in AI? Generative AI, especially Large Language Models (LLM), use statistical relevance to build responses to prompts. Literacy in education means understanding cause and effect from a text and why one observation follows another. It has to do with the real world and some understanding of how the grounding behaves and works. This kind of learning can be achieved with intelligent systems that combine AI engines with traditional programming, or in terms of the Graph Model of Combinatorial Logic: Observations and Concepts with Lambda Concepts. In conclusion, it is very helpful to listen to other disciplines for making AI intelligent. The respective task list for AI engineers includes, but is not limited to, education and teaching to children and humans.

Keywords: *artificial intelligence, generative pretrained translators, knowledge acquisition transformation, intelligent systems*

Introduction

Kausalai "Kay" Wijekumar, a professor at Texas A&M University, USA, and his team gave a talk at the 26th Annual International Conference on Education, 20-23 May 2024, collocated with Computer Science, on how to teach children to gain literacy by reading. This turned out to be an excellent tutorial on how to make an artificial neural network intelligent.

The problem with the term "Artificial Intelligence" (AI) becomes apparent when you try to translate it into other languages. In German for example, "intelligent" also means "smart", "bright", and "clever"; in Greek it includes "νουσ" which is related to the English "nous", but is probably better explained in the Iliad, where in Book 18 the (female) androids who helped Hephaistos to craft Achilles' new suit of armor are called not only intelligent, but also "νουσ". For Homer, this meant that these androids were capable not only of doing what Hephaistos said, but also of doing what he meant (Homer 1898).

Today's AI is great at intelligence in the sense of data collection, which is what the U.S. federal intelligence agencies like the FBI and CIA are called, but not at understanding what is really happening, what it means.

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Literature Review

Wijekumar's research focus on how children and pupils can become literate, which means, not only able to read and write, but understanding cause and effect, identify the ideas developed by the protagonists, summarizing the intend of the authors, able to explain what causes their behavior, and predicting consequences. As an example, we cite a recent paper about the importance of inference generation in the meaning-making process (Rice & Wijekumar 2024). However, in educational science and practice, there exists a large literature and professional associations that discuss best teaching practices that we cannot fully reference here.

More directly related to AI are contributions from other disciplines such as Theoretical Computer science that also try to shed light on how the human brain thinks. Engeler published in 2019 that the *Graph Model of Combinatory Logic* is an excellent model for "how does the brain think" (Engeler 2019). The graph model is an algebraic way of describing neural networks, i.e., directed graphs that contain loops. *Artificial Neural Networks* (ANN) do not contain loops, at least not the most prominent variety, the *Feedforward Neural Networks* (FNN). They consist of an input layer, several hidden layers and an output layer. The graph model, as combinatory logic, is Turing-complete (Turing 2004) and thus contain loops that potentially loop forever. In Computer Science, such fixpoint operators play a substantial role. It cannot be determined whether they ever stop looping. For the brain, Engeler introduces the concept of *Controlling Combinators*; loops that converge towards some *Attractor*, a construct in the neural network, aka the brain, that corresponds to a skill. As examples, he constructs controlling combinators for a violinist and for a mathematician (Engeler 2019).

The authors have shown in several papers that this graph model also serves as a general model for knowledge, with the particularity that it not only models cause-effect relations, but also allows modeling abstract concepts such as Turing programs. (Fehlmann & Kranich 2024) For practical work such as requirements engineering for AI-enabled systems, this provides the opportunity to add so-called lambda concepts that enforce rules and guarantee safe and secure operations. (Fehlmann & Kranich 2023).

Regarding classical AI based on *Large Language Models* (LLM) or any other variant of ANN, we refer to the rapidly evolving literature.as an entry point, Gerven & Bothe's classification might be a good start (Gerven & Bohte 2017). Despite the rapid advances occurred in the past few years, AI is still not able to solve basic tests found for instance in human intelligence tests, see Chollet's ARCathon, now ARC Price (Chollet 2019).

On the other hand, a team around Panigrahi at Princeton University has recently published work showing how to identify skill areas in an ANN. They use a technique called "grafting". (Panigrahi et al. 2023). This greatly simplifies the training of an ANN by allowing you to focus on some specific skill area without touching other parameters outside that skill area, and grafting allows you to implant these newly trained skills into other ANNs.

Finally, we must mention the ISO/IEC 19761 COSMIC standard for modeling software (COSMIC Measurement Practices Committee 2020). It turns out that the way software is modeled in this standard is ideally suited to the needs of intelligent systems because the model focuses on data movements, moving groups of data that can be easily identified with some specific knowledge. This allows tracing what happens to key performance indices such as reliability when data from AI engines is processed (Fehlmann & Kranich 2024).

Methodology and Methods

Intelligent systems are software-driven systems that incorporate one or more AI engines and interact with their environment either through sensors and actuators, as on the Internet of Things (López et al. 2013), or any natural or logical language. This interaction allows them to perceive whether their actions were successful or not, and to learn from failures. As such, they share some similarities with living beings, especially children and adolescents who are learning new skills (Russell 1948).

The aim of this paper is to investigate whether principles that are used in education by teachers are suitable as a blueprint for building intelligent systems, and we claim, they are.

What is Knowledge?

The graph model of combinatory logic is an interesting model for representing knowledge because the directed graphs used represent neural networks. Thus, there is a direct connection between ANN in AI, the biological brain, and this model (Fehlmann & Kranich 2024).

The constituting elements of the graph model are *Combinators*, defined as sets of arrow terms of the form (7):

$$x_j \to y \tag{7}$$

The nodes of origin in the graph x_j are a selection of *Observations*, selected by the choice function j, and the y represent the target node, the node receiving a stimulus from the x_j, also interpreted as observed effect. We call proper arrow terms *Concepts*. We claim that these combinators, consisting of observations and concepts, represent knowledge (Fehlmann & Kranich 2024). This definition is highly recursive, because you can observe concepts. Thus, arrow terms can contain other arrow terms including concepts.

If this powerset is based on the null set, weights in nodes play no role in equation (7). If the powerset is based on some non-empty set of observations referring to some real world, then you can add weights to the nodes for describing their impact on the target node and this powerset describes the behavior of both artificial and natural neural networks (Engeler 2019).

Knowledge is combined as follows. Let M and N be any combinators, then you can apply M to N:

$$M \bullet N = \{b | \exists \mathrm{a_i} \rightarrow b \in M;\ a_i \in N\} \tag{8}$$

Equation (8) makes the graph model an algebra (Engeler 1981). The algebra is Turing-complete because it is possible to define *Lambda Terms* that introduce a variable x in M, allowing for an application of M to some argument N (Barendregt & Barendsen 2000):

$$\lambda x. M \bullet N \tag{9}$$

In case of equation (9), N replaces all occurrences of $x\ in\ M$. For formal definitions, consult (Fehlmann 2020, p. 5). In the graph model, Lambda terms contain no observations; thus, it is a concept. It has the form of a complicated structural element whose application does not depend on its nodes' weights (Fehlmann 2016, p. 326ff). For this characteristic, we call it *Lambda Concept*. For a proof of Barendregt's theorem for the graph model, see Fehlmann (Fehlmann, 1981).

Barendregt's Lambda calculus means that programmable terms exist in the context of knowledge, making fixed rules part of general knowledge. For humans, this is nothing surprising; for machines, it is good to know that observation-independent rules exist like those used in social interactions between humans. Like in computer programming, you can write Lambda terms that contain no open variable terms, or you can write programs that process observations. And you can write Lambda terms that loop forever, e.g., fixpoint operators (Fehlmann & Kranich 2022).

Controlling Combinators

The basic characteristic of ANN is that there are no loops allowed from the input layer to the output layer. There are hidden layers in between but even so, they do not provide feedback. This holds not only for *Feedforward Neural Networks* (FNN); *Recurrent Neural Networks* (RNN) are bi-directional ANNs that allow the output from some nodes to affect subsequent input to the same nodes (Gerven & Bohte 2017).

In contrary, the natural brain, as well as Engeler's graph model of combinatory logic, have feedback loops by dendrites that can stimulate or attenuate responses. As in every traditional computer program, such loops can loop forever and damage neuronal reactions. Thus, the brain has mechanisms that Engeler modelled as controlling combinators. These are crucial for further developing artificial intelligence and better approximate human intellectual capabilities (Engeler 2019).

The concept of *Control* involves a *Controlling Operator* $\mathbf{C}$ which acts on a controlled object X by application $\mathbf{C} \bullet X$. Control means that the knowledge represented by X is completely known and described. It is a similar approach to establishing a fixpoint.

Accomplishing control can be formulated by:

$$\mathbf{C} \bullet X = X \tag{10}$$

The equation (10) is a theoretical statement, usually resulting in an infinite loop process. For solving practical problems, X must be approximated by finite subterms.

The *Control Problem* is solved by a *Control Sequence* $X_0 \subseteq X_1 \subseteq X_2 \subseteq \cdots$, a series of finite subterms, determined by (11):

$$X_{i+1} = \mathbf{C} \bullet X_i, i \in \mathbb{N} \tag{11}$$

starting with an initial X_0. This is called *Focusing*. The details can be found in Engeler (Engeler 2019, p. 299). The controlling operator $\mathbf{C}$ gathers all faculties that may help in the solution. Like a fixpoint combinator in combinatory logic, controlling operators are a structural element, not a single pair of observations and observed effect. The control problem is a repeated process of substitutions.

Within this setting, it is possible to define models for reasoning (Engeler 2019), problem solving, and software and systems testing (Fehlmann & Kranich 2019). Moreover, since the model includes both algorithms and cause-effect statements, it can be used for specifying requirements for intelligent systems that sometimes must adapt to the environment and sometimes follow strict rules, for instance when legal compliance, or safety, is a strict requirement (Fehlmann & Kranich 2023). While generative AI can generate any idea, reasonable or not, these algorithmic requirements, called lambda concepts, ensure predictable behavior from an intelligent system.

Intelligent systems thus are always a mix of controlling combinators and generative AI. Thus, they behave partly like an ordinary program, executing rules, and partly they interpret their environment by the data received.

The Convergence Gap

Controlling combinators need a metric that tells them whether the equation (11) actually results in a controlling sequence. Not only in AI, but this is also the most difficult question to solve: whether a change imposed on a system improves performance or not.

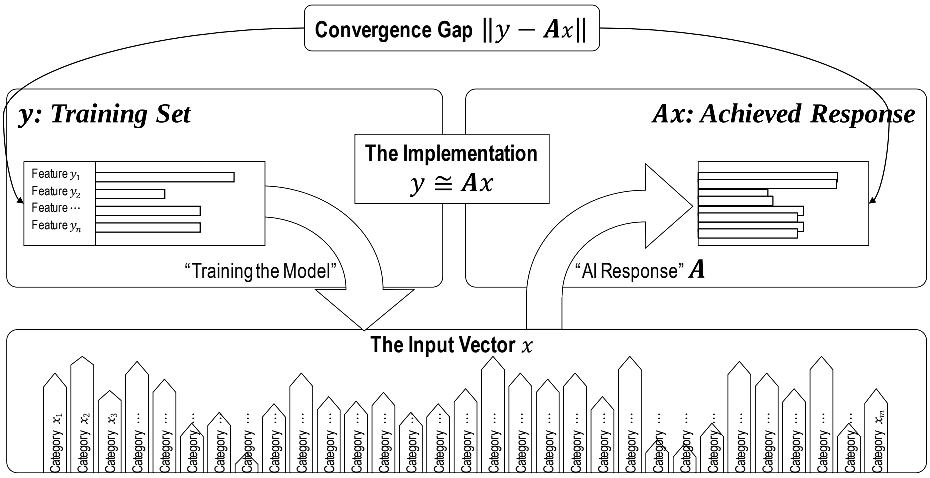
The principle of *Deep Learning* (

Figure **8**) is similar between humans and machine – it means, adjusting a transfer function $\boldsymbol{A}$ which, given an input vector $\boldsymbol{x}$, produces a response $\boldsymbol{Ax}$ that is sufficiently close to the correct answer; correct in the sense that it matches the features of the training set.

For an ANN, which here corresponds to the neural network $\boldsymbol{A}$, the weights of the nodes is adjusted so that the response vector $\boldsymbol{Ax}$ matches the training features

$\boldsymbol{y}$ as best as possible. The difference between $\boldsymbol{y}$ and $\boldsymbol{Ax}$ is called *Convergence Gap*. This difference is calculated by the Gauss' method of the least squares (Stigler 1981).

Figure 8. *The Principle of Deep Learning*

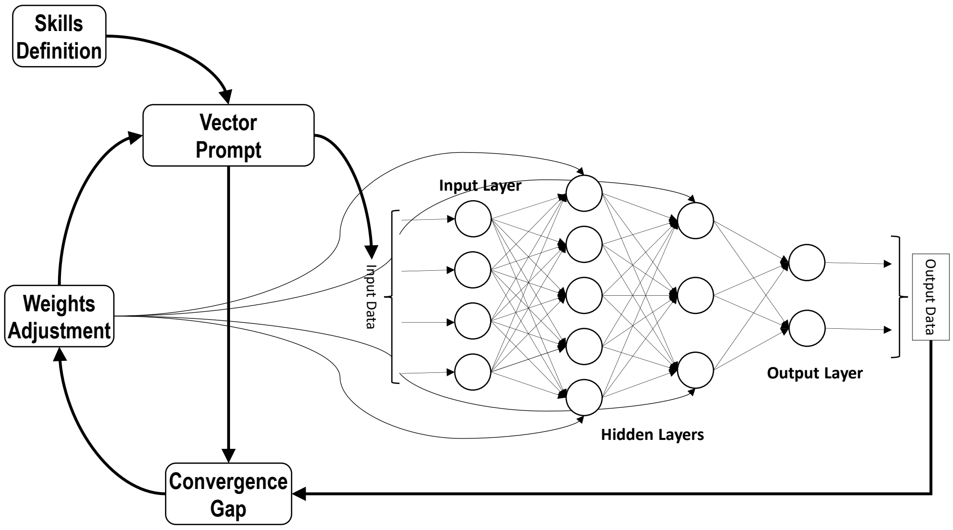


Implementing Controlling Combinators

Although neural networks are well capable of learning algorithmic programming (Fehlmann & Kranich 2024), implementing controlling combinators in an ANN is difficult by the lack of feedback loops. Thus, the feedback loops have to be provided by some embedding environment, for instance Phyton that runs most of the ANNs.

The requirements for a controlling combinator include the ability to deal with potentially infinite calculations and repetitions executed by an ANN. This includes the ability to stop the ANN's learning cycle once the precision achieved is good enough. This is measured by the convergence gap but requires some upfront definition of what means "good enough". Usually, in all kinds of undertaking, this is the most difficult step.

Figure 9. *Controlling Combinator Implementation Scheme*



According to Figure 2, a controlling combinator implements at least the following three functional processes: prompting, convergence gap calculation, and parameter adjustments in the ANN, here represented by its input and output layer, plus two or more hidden layers (Gerven & Bohte 2017).

The basic principle of a controlling combinator has some similarities with deep learning. The controlling sequence is implemented by adjustments to the parameters of the AI engine, e.g., the weights in an ANN. However, contrary to deep learning, the controlling combinator can adapt the criteria for good learning to what the systems learned before. The controlling combinator consists of three functional processes:

> The first functional process supplies the training set to the respective part of the AI engine. This is called *Skills Definition*. This functional process might need to access one or several knowledge bases, and the Internet.
> The second functional process measures the success rate of the controlling sequence and is called *Convergence Gap*. This functional process needs access not only to knowledge bases but also to operational data representing an actual status of a system, such that it can compare responses from the AI to factual evidence.
> The third functional process adjusts the parameters of the AI engine (e.g., the weights of an ANN) according to some suitable learning strategy. The controlling combinator repeats operations until the convergence gap closes sufficiently well.

The convergence gap usually does not reach zero because that would mean we have a deterministic system that might violate the undecidability of predicate logic, consult Gödel (1931) and Raatikainen (2020).

Applying Controlling Combinators to Literacy

Wijekumar's *Knowledge Acquisition Transformation* (KAT) framework consists of the following six steps:

1) Learn Vocabulary – basic reading skills.
2) Text Reading – text in full detail.
3) Guide Thinking – try to identify ideas.
4) Important Ideas – which ideas matter?
5) Summarize Main Ideas – reproduce relevant ideas.
6) Extrapolate Inferences:
    - Get the mechanics of the plot;
    - Become able to reproduce it.

For step 3 – Guide Thinking – Wijekumar proposes a logical schema, the Cause-Problem-Solution principle. This can be understood as a logical framework that links elements of the plot together – such as in book 9 of the Iliad, where Achilles' rage does not allow him returning under the command of Agamemnon. The solution of the problem is sending Patroclus instead. This then causes new problems (Homer 1898).

To implement the KAT framework, we need a controlling combinator for each of the six steps:

1) Pre-Trained LLM – You can start with any pre-trained LLM.
2) Fine-tune LLM with text – You should train the LLM with the specific text, e.g., Homer, or some Netflix plot.
3) Extract **C**ause-**P**roblem-**S**olution triplets – Do a structural analysis of what you read. This involves that the intelligent system uses a logical model – the C-P-S triplets – to collect cause-effect ideas from the text.
4) Logically combine C-P-S triplets – we might need to use the services of a logical engine to do that.
5) Find proofs – sequences of logically dependent C-P-S triplets that lead to some conclusion that fits the plot.
6) Let the LLM explain the plot as a logical sequence.

Basically, we adapt these six steps to understand the learning cycles of an intelligent system. While step one and step two (pre-learning and fine-tuning) are following today's standards in deep learning, step three involves a logical structure that exists outside the LLM. It will be used for training the LLM in logical skills. In some sense, the traditional logic represented by the C-P-S triplets complements the language skills available in the LLM. This makes, in turn, the responses of the LLM explainable. The fourth and the fifth step are well controllable by the Controlling Combinator in the sense, that a Convergence is easily calculated that identifies correct logic and whether the resulting effect have some relevance to the original text.

Intelligent means in this context that some continuous learning occurs after initial pre-training and fine-tuning of the large language models (LLM). It's an interesting question that we cannot answer yet, whether original texts like the Iliad or modern, derived plots, e.g., from Netflix, work better. The full KAT implementation design can be found in a collection of Intelligent System designs by Euro Project Office (Fehlmann 2024).

In any case, intelligent systems are a mix of traditional, algorithmic programming and generative AI engines based on ANN like the currently emerging LMM. No design for an AI engine currently supports self-paced learning without help from algorithmic programming, usually in Python. For this, we introduce the software modelling approach following ISO/IEC 19761.

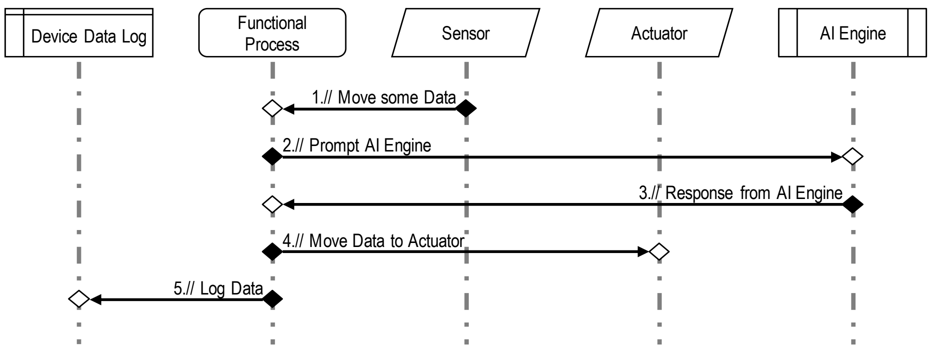
The ISO/IEC 19761 Model of Software (COSMIC)

As an ideal tool for designing intelligent systems, we use the ISO/IEC 19761 model of software (ISO/IEC 19761, 2019). This model introduces the concept of *Data Group* (COSMIC Measurement Practices Committee 2020, p. 13), a group of logically connected data describing objects of interests from the user's perspective. The data groups are moved between a functional process and devices, other application, or permanent storage. The model distinguishes four types of data movements: Entry, eXit, Read and Write. It is easy to identify the data groups as specific sets of knowledge that are moved from one object of interest to another. Thus, data movements carry the knowledge acquired by the intelligent system.

The AI part of the intelligent system is modelled as "another application". Its response might be subject to some uncertainty.

Similar to UML diagrams, we represent software as *Data Movement Maps*, identifying objects of interest with lifelines and let the data movements execute between them. This yields a rough description of the software modelled. It can be used to measure reliability of an intelligent system (Fehlmann & Kranich 2024) but does not specify the exact execution of loops in a program. Nevertheless, it carries enough detail to allow for the representation of controlling combinators that support intelligent systems when learning behavior and details of its environment.

Figure 10. *Sample Data Movement Map Driven by an AI Engine Application*



Results

This research started by end of May 2024 and will be continued for some time. Preliminary results suggest learning from other disciplines is probably the king's way towards intelligent systems. It is not helpful to dismiss older attempts as "failures" only because they did not meet expectations – that always were too high, usually – and because current LLMs outperform all previous attempts to handle natural language.

A Sample Implementation of KAT

Currently, only a design exists for the KAT implementation in the form of a commented data movement map. We are looking for partners to implement them in a real system. KAT is not a small intelligent system. With its six times three functional processes, implementing six controlling combinators for learning reading skills in the sense of literacy, it counts a few hundred data movements, i.e., COSMIC function points. Its reliability – a performance measurement (Fehlmann & Kranich 2024) – depends on the choices for the thresholds for the six convergence gaps (Hunt 2003).

Applying the Method to Other Challenges

Conceptualization is a challenge for all kinds of LLM. The ARC Price challenge (formerly ARCathon) is still open (Chollet 2019). So far, no approach is known that lets an LLM learn the rather basic conceptualization skills that are needed to solve the ARC Price puzzles, while an average human is easily capable to perceive the rules behind the puzzling drawings and thus solving the ARC Price challenge.

Our method to train an LLM with logical patterns such as the S-P-S triplets should also work for the ARC Price challenge.

Discussion

The big challenge in our approach is getting the convergence gap right. This is what made Wijekumar's work so attractive for us; we learned from her work how to set up suitable convergence gaps for our learning task.

It is not obvious from the design that LLMs can be efficiently trained to do logic. It may well be that another AI engine is better suited for logical reasoning. On the other hand, an ANN is inherently capable of logic because of the shared representation of knowledge (Fehlmann & Kranich 2024) and Barendregt's Lambda theorem. Nevertheless, it might be a different approach than just implementing arrow terms for logical deduction in a neural network. Humans, for example, often do logic by combining language skills and visual imagination of logic rules and logical deduction (at least the author does), but the approaches are likely to be different for each individual.

Conclusions

Making AI intelligent is still a big challenge. We believe that while the impact of LLMs and large ANNs is great and their achievements are stunning, there are many open questions. One is called "Explainable AI" and refers to the problem that it is very difficult to understand an AI decision. Somehow it relates to the training set, its possible biases and shortcomings. Intelligent systems, as we propose them, should be able to combine AI reasoning with adherence to rules, regulations, and safety-first principles, while at the same time improving the system by using control combinators for continuous learning.

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