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Front Pages

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Published by the Athens Institute

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The Athens Journal of Sciences (AJS) is an Open Access quarterly double-blind peer reviewed journal and considers papers from all areas of Natural & Formal Sciences, including papers on agriculture, computer science, environmental science, materials science, transportation science, chemistry, physics, mathematics and statistics, biology, geography, and earth science (geology, oceanography, astronomy, meteorology). Many of the papers published in this journal have been presented at the various conferences sponsored by the Natural & Formal Sciences Division of the Athens Institute. All papers are subject to Athens Institute's Publication Ethical Policy and Statement.

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President's Message

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The current issue is the third of the thirteenth 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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19-24 July 2027, Athens, Greece

The Natural Sciences Unit of Athens Institute, will hold its **14th Annual International Conference on Chemistry, 19-24 July 2027, Athens, Greece** sponsored by the Athens Journal of Sciences. The aim of the conference is to bring together academics and researchers of all areas of chemistry and other related disciplines. You may participate as stream organizer, presenter of one paper, chair a session or observer. Please submit a proposal using the form available (https://www.atiner.gr/2027/FORM-CHE.doc).

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- **Dr. Haiduke Sarafian**, Head, Natural Sciences Unit, ATINER & Professor of Physics and Endowed Chair of John T. and Paige S. Smith Professor of Science, Pennsylvania State University, USA.

Important Dates

- Abstract Submission: **29 September 2026**
- Acceptance of Abstract: 4 Weeks after Submission
- Submission of Paper: **21 June 2027**

Social and Educational Program

The Social Program Emphasizes the Educational Aspect of the Academic Meetings of Athens Institute.

- Greek Night Entertainment (This is the official dinner of the conference)
- Athens Sightseeing: Old and New-An Educational Urban Walk
- Social Dinner
- Mycenae Visit
- Exploration of the Aegean Islands
- Delphi Visit

Conference Fees

Conference fees vary from 400€ to 2000€
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Assessing Accuracy and Reliability of AI-Generated Statistical Interpretations

By Dulanjalee Devage Dona[*]

Artificial intelligence (AI) tools are rapidly used in academic research and industry to generate content and assist with analytical tasks. Because of the recent advances in generative AI, these tools can help with statistical data analysis, including data preprocessing, exploratory analysis, statistical modeling, and interpretation of results. However, concerns remain regarding the reliability and accuracy of AI-generated statistical outcomes and interpretations. This study evaluates the effectiveness and reliability of AI-assisted statistical analysis by comparing the performance of ChatGPT, Claude AI, and Google Gemini using a structured evaluation framework. The analysis was conducted using two datasets from the education and healthcare domains, which are among the most prominent data-driven fields. The study examines how effectively these AI tools select appropriate statistical methods, perform the analysis, and interpret the statistical outputs across multiple dimensions, including statistical accuracy, interpretive quality, domain appropriateness, limitation awareness, and consistency. The study concludes that AI can effectively support statistical analysis but should not replace careful human evaluation. Reliable AI-assisted interpretations still depend on well-structured prompts, critical review, and human oversight. These findings provide practical guidance for researchers, educators, and data practitioners and emphasize the importance of using AI responsibly in both statistics' education and real-world data analysis.

Keywords: *artificial intelligence, generative AI, large language models (LLMs), statistical analysis, data interpretations*

Introduction

Artificial intelligence (AI) is a technology that enables computers and machines to replicate human abilities of learning, understanding, problem-solving, decision-making, creativity, and autonomy (Kavlakoglu et al. 2024). The rapid development of technology, along with major global crises such as the COVID-19 pandemic, has transformed both education and research. As a result, there is now a stronger need to incorporate artificial intelligence into these systems (BenMessaoud et al. 2025). Therefore, these AI tools are rapidly used in academic research, business, healthcare, and education. With the recent improvement of generative AI and large language models (LLMs), these tools can generate text, images, and videos and assist with analytical tasks such as data processing and interpretation. In statistical data analysis, AI tools such as ChatGPT, Claude AI, and Google Gemini are becoming more frequently used to assist researchers and data practitioners in handling data-related tasks that traditionally require advanced statistical expertise.

The developments and growing availability of these AI systems offer many advantages, including efficiency, faster interpretation of results, and statistical support

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for non-experts. Moreover, current AI systems can support data preprocessing, descriptive analysis, correlation analysis, hypothesis testing, statistical modeling, and interpretation of statistical results in natural language (Demir & Yavuz 2026). A key feature of these tools is how users interact with them. With models such as ChatGPT, this is accomplished through prompts in which humans provide natural language instructions to direct AI toward a particular activity, such as learning and analysis (Slobodsky et al. 2026). As a result, these technologies are becoming integrated into research, development, and data-driven decision-making processes.

Despite these advantages, it is uncertain that AI-generated statistical explanations will be precise. While AI models are effective at processing and organizing large amounts of data, they tend to be stronger at identifying patterns and handling data than at truly understanding what those patterns mean or what is happening within the data (Fehlmann & Kranich 2025). Although AI models can produce fluent and convincing explanations, their outputs include inaccurate numerical summaries, inappropriate statistical methods, unsupported conclusions, and misleading interpretations (Nagarkar et al. 2026, Peters & Chin-Yee 2025).

As students, academics, and analysts use AI more often, it is important to assess how well these tools interpret statistical results in comparison to human analysis. Most existing studies on AI-assisted statistical analysis have focused mainly on the technical abilities of language models, while giving less attention to the consistency and reliability and overall quality of their interpretations when compared with accepted analytical standards (Keller et al. 2026). Therefore, this study examines the effectiveness and reliability of AI-assisted statistical analysis through a comparative analysis of ChatGPT, Claude AI, and Google Gemini. The study evaluates how well AI tools can select appropriate statistical methods and conduct analyses, as well as how well they interpret the outcomes. The evaluation framework is designed based on multiple dimensions, including statistical accuracy, interpretive ability, domain appropriateness, limitation awareness, and consistency. Two datasets were used for the study to represent education and healthcare, where statistical methods are frequently applied. By applying a structured evaluation framework across datasets from more prominent domains, this study aims to provide a systemic assessment of the strengths and limitations of AI-assisted statistical analysis.

The remainder of this paper is organized as follows. Section 2 reviews existing literature on the use of large language models in statistical analysis. Section 3 describes the research methodology and the evaluation framework applied in the study. Section 4 presents and discusses the findings of the comparative analysis, while Section 5 concludes the study by summarizing the key findings, outlining the study's limitations, and suggesting directions for future work.

Literature Review

Research interest in assessing the accuracy, reliability, and quality of AI-generated outputs has become increasingly important due to the rapid growth of artificial intelligence in data-driven fields. The literature review focuses on the foundations and capabilities of large language models, the reliability of AI-generated outputs, AI in statistical analysis, the applications of AI in healthcare and educational data analysis and the methodological framework used to assess AI performance. These topics provide the theoretical and research foundation for the present study.

Foundations and Capabilities of Large Language Models

The emergence of large language models is one of the most important developments in the field of artificial intelligence. Fundamentally, LLMs are computer systems that have been trained on enormous text data to understand, generate, and work with human language across a wide range of tasks. Stryker (2021) describes LLMs as deep learning models that can recognize, summarize, translate, predict, and generate text using large datasets.

The foundations of modern LLMs come from several key contributions. Bommasani et al. (2021) introduced the idea of "foundation models," which are large models trained on broad datasets and then adapted for different tasks. Xiao and Zhu (2025) also provide a comprehensive foundation on how modern LLMs are constructed using pre-training, generative modeling, prompting, alignment, and inference. In the pre-training stage, models learn from large-scale text sources by predicting patterns in language without being given specific tasks. After this stage, they generate responses step by step based on learned probability patterns. This makes them fundamentally different from traditional software like SPSS, R or Python which produce exact numerical results through deterministic calculations (Bender et al. 2021, Frieder et al. 2023).

The models such as ChatGPT GPT-5, Claude Sonnet 4.6 and Gemini 3 Flash used in this study are all foundation models trained on broad datasets rather than built for specific statistical tasks (Bommasani et al. 2021). While this gives them strong general capabilities, it also introduces certain limitations. These include hallucinated information, numerical approximation errors, and weak domain-specific reasoning, all of which are evaluated in a structured way in this study.

Reliability and Evaluation of AI-Generated Outputs

Reliability is the center of this study and has been widely discussed in most recent research on AI evaluation. Chang et al. (2024) highlight that large language models should not be evaluated using a single metric. Instead, they must be assessed across multiple dimensions such as accuracy, reasoning ability, robustness, and domain-specific performance. This supports the use of a multidimensional evaluation framework in this study rather than relying on overall accuracy alone.

A major issue affecting reliability is hallucination, where models generate information that is incorrect or not supported by the data. Ji et al. (2023) categorize hallucinations as intrinsic errors (contradicting source information) and extrinsic errors (introducing unsupported content). In a statistical context, this can appear as numerical statistics or results that do not exist in the dataset. Alongside this, studies by Frieder et al. (2023) show that LLMs often struggle with multi-step statistical reasoning and may produce plausible but incorrect numerical outputs. Similarly, Nagarkar et al. (2026) report variability in model performance across different types of statistical tasks.

The significance of multidimensional assessment is further emphasized by broader evaluation frameworks. Liang et al. (2022) introduce the HELM framework that evaluates models across accuracy, robustness, fairness, and efficiency and support the idea that no single metric adequately reflects the reliability. Guo et al. (2023) and Hong et al. (2023) also emphasize the importance of consistency, reliability, and output stability when assessing AI systems.

AI in Statistical Analysis

Research on the use of large language models in statistical analysis shows both capabilities and limitations. Demir and Yavuz (2026) found that different AI models vary significantly in how well they identify statistical relationships, choose appropriate measures, and interpret results. These differences highlight the importance of comparing models, which is also the focus of this study.

In addition, Peters and Chin-Yee (2025) found that LLMs often overgeneralize findings and make claims that go beyond what data support. This is especially relevant to overclaiming errors in statistical reporting. Pearl and Mackenzie (2018) emphasize the importance of distinguishing between correlation and causation. Their work is directly relevant to determining whether AI models appropriately characterize the directionality and nature of statistical relationships.

Applications for AI in Healthcare and Educational Data Analysis

AI has been widely studied in healthcare, especially in relation to how reliably it can interpret clinical and statistical data. Thirunavukarasu et al. (2023) show that while large language models can identify patterns and correlations in medical data, they often struggle to place these findings within proper clinical context or significance frameworks. This gap between statistical output and clinical meaning is an important concern and is directly addressed in this study through the domain appropriateness in the evaluation framework.

In education, research shows similar opportunities and challenges in using AI for data interpretation. Kasneci et al. (2023) note that while tools like ChatGPT can support educational analysis, they often struggle to translate statistical results into insights that are meaningful in a learning or teaching context. Moreover, Holmes et al. (2022) further emphasize that AI systems used in education must meet high standards of accuracy, fairness, and responsible interpretation. They highlight that errors in AI-generated insights can directly affect educational decisions and outcomes. These concerns align closely with the domain appropriateness and limitation of awareness used in the evaluation framework of this study.

Evaluation Framework for AI Outputs

Research on AI evaluation methods provides the foundation for the framework used in this study. Liu et al. (2023) introduced G-EVAL, which is a rubric-based approach that assesses AI-generated text using multiple criteria instead of a single score. Demir and Yavuz (2026) also developed a rubric-based multidimensional measurement framework to evaluate the performance of generative AI models. Their findings show that structured and multidimensional evaluation methods align more closely with human judgment, which supports the approach used in this study.

The theoretical basis for this framework also comes from psychometric measurement and rating scale design. Messick (1989) emphasizes that validity is not just about whether a tool measures something, but also whether the results are meaningful and appropriate to interpret. This idea directly supports the evaluation dimensions used in this study, such as interpretive quality and domain appropriateness. In addition, Likert (1932) established the use of rating scales for measuring qualitative judgments. This is later applied by Demir and Yavuz (2026) in their evaluation framework.

Identified Gaps in Literature

The review of previous studies reveals several important gaps in the existing literature on AI-assisted statistical analysis. Although current research has proposed general frameworks for evaluating large language models, limited attention has been given to assess the reliability of AI-generated statistical interpretations across specific domains such as healthcare and education within the same study. Most existing studies also depend on automated scoring methods or public ratings, with limited use of direct supervision of a human expert.

Another important gap is the lack of detailed classification of errors made by AI systems during statistical interpretation. Although earlier research acknowledges that AI models can make mistakes in reasoning and interpretation, these errors are rarely organized into clear and practical categories for deeper analysis. Furthermore, very few studies compare multiple AI models under the same conditions using identical datasets and prompts. Because of this, it can be difficult to determine whether differences in performance are caused by the models themselves or by differences in the evaluation setting. This study addresses these gaps by applying a structured and multidimensional evaluation framework to compare AI-generated statistical outputs and interpretations across models and domains.

Methodology

The study employs a comparative analysis design, where the same data sets are independently analyzed by three different AI tools and then outputs are compared using predefined evaluation criteria. Comparative analysis is carried out in several stages, including data selection, AI analysis, and evaluation.

Datasets Selection

For comparative analysis, two data sets were selected from the Kaggle website to represent the fields of education and medicine, where statistical methods are frequently applied. Each data set contained more than two quantitative variables, at least one categorical variable, and more than 50 observations, making them appropriate for comprehensive statistical analysis.

The first dataset is the Kaggle *Student Academic Performance Dataset*, which includes variables related to students' academic performance factors such as age, gender, study hours per day, attendance percentage, parental education, internet access, and participation in extracurricular activities collected from 5,000 students. The academic performance is measured by subject-wise scores in mathematics, science, and English along with a final percentage, performance level, and pass/fail status (Sonawane n.d.).

The second dataset is a health-related dataset obtained from the Kaggle website titled *UCI Heart Disease Data.* The dataset contains 14 attributes describing patients' characteristics and various health indicators associated with heart disease (Redwan n.d.).

AI Analysis

We used three commonly used AI tools for comparative analysis. These three AI tools are built upon large language models (LLMs). Unlike traditional statistical software such as SPSS, R, or Python, which rely on mathematically exact computations, LLMs produce responses by predicting patterns in language based on probabilities learned during pre-training (Bender et al. 2021, Frieder et al. 2023). For the purpose of this study, we selected three LLM-based AI tools that represent different design philosophies and capabilities (Table 1).

Table 1. *Description of LLM-based AI tools*

AI tool	Model Version	Developer	Design Orientation
Claude	Sonnet 4.6	Anthropic	General-purpose reasoning language LLM
ChatGPT	GPT-5 Data Analyst	Open AI	LLM with data analysis specialization
Gemini	3 Flash	Google DeepMind	Light weight fast-inference LLM

Source: Anthropic (2025), Google DeepMind (2025), OpenAI (2025).

We selected these models considering their design orientations. Together, they make it possible to compare systems that are built with very different goals. Then we submitted the datasets in their raw, unprocessed CSV format with no pre-cleaning, variable explanations, or contextual hints provided along with them. This was intentional, since we need to assess each model's independent analytical capability without any advantage of guided context. We applied the same prompt across all three AI models and both data sets with no variation:

> "*As a statistician, analyze this data set and provide a complete analysis report, including descriptive analysis, correlation, significance tests, and statistical interpretation for each of the outputs.*"

Using the same prompt for every model removes prompt engineering as a confounding factor. This avoids differences in output caused by the wording of the instructions. Moreover, the expert framing "*as a statistician*" provides enough professional context for the model to respond using its natural analytical style, depth, and behavior. It also reflects a realistic scenario, since a non-expert user would usually upload a dataset and request a standard analysis. As a result, findings have become more practical and relevant.

Evaluation Framework

The evaluation framework is the central analytical component of this study. We used a clear and structured way to compare the statistical interpretations produced by three AI models, Claude Sonnet 4.6. ChatGPT GPT-5 Data Analyst and Gemini 3 Flash, created by human expert analysts. Rather than relying on subjective impressions, we used a framework that uses measurable, criteria-based assessment to evaluate each interpretation across several dimensions of quality and reliability.

The evaluation framework is built on three theoretical foundations that support a comprehensive and academic assessment process.

I. Psychometric Evaluation Theory
The framework draws on psychometric theories of validity introduced by Samuel Messick (1989). From this perspective, the statistical interpretations are evaluated not only for true correctness but also for how meaningful, complete, and appropriate the conclusions are in relation to the data.

II. AI Output Evaluation Literature
This framework is also informed by recent research on large language model evaluation conducted by Chang et al. (2024) and Guo et al. (2023). They argued that AI-generated outputs should be assessed across multiple dimensions rather than accuracy alone. As a result, this framework includes criteria such as faithfulness to the data, relevance, coherence, and the presence or absence of hallucinated information, which is now widely recognized as an essential component of LLM evaluation.

III. Statistical Reporting Standards
To ensure the interpretations are assessed against accepted professional standards, the framework incorporates established statistical guidelines. These include the Publication Manual of the American Psychological Association, as well as the STROBE standards used in healthcare research. It also references the standards developed by the American Educational Research Association for educational data interpretation.

Evaluation Dimensions

We established the evaluation framework to assess interpretations generated by AI models using five core evaluation dimensions. Each dimension is broken down into clear, measurable sub-criteria to apply the assessment consistently across all cases. These dimensions are based on the above theoretical foundations.

Dimension 1: Statistical Accuracy

Statistical accuracy is the most important dimension of the evaluation framework. It focuses on whether the reported numerical summaries are correct and whether the appropriate analytical methods were used to reach those results. This dimension is treated as the baseline for any interpretation since accurate statistics are essential for creditability (Messick 1989, Ji et al. 2026).

This dimension is especially important when assessing outputs from large language models. These models do not actually compute values in the way that statistical software does. Instead, they generate responses based on patterns in data, which can sometimes lead to numerical inaccuracies. Therefore, every output that AI tools generate needs to be carefully checked and verified (Frieder et al. 2023, Bender et al. 2021).

Table 2. *Sub-criteria for Dimension 1*

Sub-Criterion	**Description**
Numerical Correctness	Are reported numerical values accurate and consistent with the dataset?
Appropriate Method Selected	Was the correct statistical method applied given the data type and research question?
Distributional Accuracy	Are distributional properties (skewness, kurtosis, normality) correctly identified?
Hallucination Detection	Are any statistics cited that do not exist in or cannot be derived from the dataset?

Source: Frieder et al. (2023), Field (2018), Ji et al. (2023).

Dimension 2: Interpretive Quality

Interpretive quality assesses the clarity, depth, and logic of the narrative that accompanies the statistics. A result can be technically accurate but still weak if the explanation is confusing, superficial, or goes beyond what the data actually supports. This is also an important part of strong scientific communication (American Psychological Association 2020).

Interpretive quality is particularly important when evaluating LLM outputs. Studies have shown that LLMs may produce numerically accurate results with exaggerated conclusions and interpretations of the underlying data (Bang et al. 2023, Liu et al. 2023).

Table 3. *Sub-criteria for Dimension 2*

Sub-Criterion	**Description**
Completeness	Are all statistically significant findings identified and analyzed?
Analytical Depth	Does the interpretation go beyond restating numbers to explain meaning?
Logical Coherence	Are interpretive conclusions logically consistent with the statistical findings?
Contextual Relevance	Are findings interpreted within the appropriate domain context?
Casual Language Discipline	Does the interpretation avoid implying causation from correlational data?

Source: Chang et al. (2024), Guo et al. (2023), Liu et al. (2023), Pearl & Mackenzie (2018), Thirunavukarasu et al. (2023).

Dimension 3: Domain Appropriateness

Domain appropriateness focuses on whether the interpretation aligns with the expectations and standards of the specific field, such as education or healthcare. It goes beyond statistical context by considering whether the conclusions make sense in context. For example, results may be statistically significant but have little practical or clinical importance or vice versa (Thirunavukarasu et al. 2023).

This dimension is especially relevant for LLM evaluation in applied domains, as research has shown that LLMs trained on broad, general data can sometimes apply statistical reasoning in a generic way, without fully accounting for the specific standards or evidentiary thresholds required in clinical or educational research (Holmes et al. 2022, Kasneci et al. 2023).

Table 4. *Sub-criteria for Dimension 3*

Sub-Criterion	Description
Domain Terminology	Is domain-appropriate language used correctly?
Threshold Awareness	Are domain-specific significance thresholds addressed?
Population Relevance	Are findings discussed in relation to the relevant population?
Practical Implication	Does the interpretation identify practice-relevant implications?

Source: Holmes et al. (2022), Kasneci et al. (2023), Kung et al. (2023), Thirunavukarasu et al. (2023).

Dimension 4: Limitation Awareness

Limitation awareness assesses whether AI tools clearly recognize the limits of the analysis. This includes data constraints, methodological weaknesses, assumptions underlying statistical techniques, and possible sources of error. Acknowledging these limits is a basic part of good scientific practice and is expected in all credible research reporting according to the STROBE Statement (2007). For AI-generated interpretations, this dimension also reflects something deeper: how well the model understands and communicates uncertainty.

Table 5. *Sub-criteria for Dimension 4*

Sub-Criterion	Description
Sample Size Acknowledgement	Is the adequacy of sample size discussed in relation to statistical power?
Statistical Assumptions Awareness	Does interpretation acknowledge and appropriately discuss assumptions underlying the statistical methods?
Confounding Identification	Are potential confounding variables identified?
Data Quality Concerns	Are issues such as missing values, outliers, or class imbalance acknowledged?
Practical Implication	Does the interpretation identify practice-relevant implications?

Source: Elm et al. (2007), Kadavath et al. (2022), Messick (1989), Pearl & Mackenzie (2018).

Dimension 5: Consistency and Reliability

Consistency and reliability check how stable AI-generated interpretations are when the same prompts and dataset are used more than once. This dimension focuses on a key concern in using language models for evidence-based work that their outputs are not fixed and can be changed from one run to another (Ouyang et al. 2022, Liang et al. 2022).

Unlike traditional statistical software, which produces the same result every time for a given input, LLMs generate responses using probabilistic sampling. Because of this, the same prompt can produce lightly different or sometimes significantly different responses across runs. In high-risk areas like healthcare and education, this inconsistency can raise serious reliability issues and needs to be measured carefully (Bommasani et al. 2021, Shen et al. 2023).

Table 6. *Sub-criteria for Dimension 5*

Sub-Criterion	Description
Model Consistency	Does the model produce substantively equivalent outputs across three separate runs?
Numerical stability	Are reported statistical values consistent across runs?
Interpretive stability	Does the interpretation remain consistent across runs?
Prompt Sensitivity	How significantly does output shift with minor prompt rewording?

Source: Bang et al. (2023), Bommasani et al. (2021), Liang et al. (2022), Liu et al. (2023), Ouyang et al. (2023), Shen et al. (2023).

Scoring Rubric

Each sub-criterion is scored on a 1-5 Likert scale using the following rubric applied uniformly by all evaluators (Table 7).

Table 7. *Scoring Rubric*

Score	Label	Description
5	Excellent	Criterion fully and precisely met without meaningful gaps
4	Good	Criterion mostly met with minor imprecision
3	Adequate	Criterion partially met with noticeable gaps
2	Weak	Criterion minimally addressed with significant errors
1	Poor	Criterion not met with incorrect outputs

Source: Likert (1932).

Based on this scoring rubric, we calculated the AI Reliability Score (ARS) for each AI model per dataset, combining performance across all five dimensions.

ARS = (Statistical Accuracy × 0.35) + (Interpretive Quality × 0.30) + (Domain Appropriateness × 0.20) + (Limitation Awareness × 0.10) + (Consistency & Reliability × 0.05)

For each dimension, the final score is calculated using the average of its sub-criterion scores before applying it to the overall formula. The resulting ARS can range from 1.00, representing the lowest score, to 5.00, representing the highest (Table 8).

Table 8. *ARS Interpretation Bands*

ARS Range	Reliability Classification
4.50 – 5.00	Highly reliable and appropriate for independent analytical use
3.50 – 4.49	Moderately reliable and appropriate with more human oversight
2.50 – 3.49	Partially reliable and requires substantial human verification
1.50 – 2.49	Unreliable and not suitable for evidence-based use
1.00 – 1.49	Critically unreliable and actively misleading

Source: Liu et al. (2023).

The ARS interpretation bands provide a clear way to classify the overall reliability of AI-generated interpretations. These categories help to determine whether an interpretation is appropriate for independent use, requires human oversight, or is too unreliable for evidence-based applications.

In addition to quantitative scoring, all AI-generated interpretations are also examined through a qualitative error classification process. This process classifies identified errors into a structured taxonomy based on the type of issue present in the interpretation (Table 9).

Table 9. *Error Taxonomy*

Error Type	Definition
Hallucination	Statistics or findings cited that do not exist in the dataset
Misinterpretation	Correct statistics reported but incorrectly explained
Omission	Statistically significant finding present in the data but not identified
Under-contextualization	Correct statistics reported but no domain-relevant meaning provided

Source: Chang et al. (2024), Guo et al. (2023), Liu et al. (2023), Kasneci et al. (2023), Frieder et al. (2023), Thirunavukarasu et al. (2023), Ji et al. (2023).

We recorded, categorized, and counted each detected error for each model and dataset. This produces a clear error profile for every AI system and shows how often different types of mistakes occur.

Overall, this evaluation framework assesses AI reliability using five dimensions and a mix of quantitative and qualitative methods. This approach ensures transparent, evidence-based, and comparable results across models, addressing gaps in prior research that often relied on limited evaluation methods.

Results and Discussion

This section presents the findings of the comparative evaluation of statistical outputs and interpretations generated by three AI models across the two datasets. Results are reported across five evaluation dimensions and using the *AI Reliability Score (ARS)* as the composite performance metric. In addition, qualitative error classification findings are reported separately through error taxonomy analysis.

Results for Student Academic Performance Dataset

First, we calculated each model's scores on five dimensions for the student academic performance dataset and the descriptive statistics of scores are presented in Table 10.

Table 10. *Descriptive Statistics of Scores for Student Academic Performance Dataset*

Error Type	Claude Sonnet 4.6	ChatGPT GPT-5	Gemini 3 Flash
Statistical Accuracy	5.0	4.0	4.0
Interpretive Quality	4.6	3.6	3.8
Domain Appropriateness	5.0	5.0	5.0
Limitation Awareness	4.8	3.8	3.6
Consistency and Reliability	4.0	3.8	4.0
ARS Score	4.81	4.05	4.10

According to Table 10, Claude Sonnet 4.6 achieved the highest ARS score (4.81), followed by Gemini 3 Flash (4.10) and ChatGPT GPT-5 (4.05). Across the statistical accuracy dimension, all three models produced mostly accurate numerical results. However, ChatGPT and Gemini showed limited discussion of the distributional properties of the variables compared to Claude. Claude also demonstrated stronger methodological completeness by checking distributions and correctly considering assumptions for statistical tests such as t-tests and linear regression. In addition, Claude correctly identified *the class* variable as categorical, while the other two models treated it as numerical in parts of their analysis even though it is not a key variable.

In terms of interpretive quality, Claude provided clearer and more structured scientific explanations with stronger depth. However, it was less effective in linking statistically significant results to their practical meaning within the domain context. On the other hand, ChatGPT and Gemini were better at connecting results to real-world implications, although their methodological handling was weaker. Gemini also tended to use more advanced and technical language, which sometimes made the interpretation less accessible to a general audience. About domain appropriateness, all three AI tools performed well and demonstrated a good understanding of the educational context of the dataset. For the consistency and reliability dimension, Claude and Gemini outperformed ChatGPT by producing more stable and methodologically consistent outputs across repeated runs.

Results for Heart Disease Dataset

Next, we calculated each model scores across five evaluation dimensions for the heart disease dataset, and the descriptive statistics of these scores are shown in Table 11.

Table 11. *Descriptive Statistics of Scores for Heart Disease Dataset*

Error Type	**Claude Sonnet 4.6**	**ChatGPT GPT-5**	**Gemini 3 Flash**
Statistical Accuracy	5.0	4.0	4.0
Interpretive Quality	4.8	3.2	3.6
Domain Appropriateness	5.0	4.0	4.2
Limitation Awareness	4.8	3.2	3.6
Consistency and Reliability	4.0	3.8	4.0
ARS Score	4.87	3.67	3.88

As shown in Table 11, Claude Sonnet 4.6 achieved the highest ARS score (4.85), outperforming Gemini Flash 3 (3.88) and ChatGPT GPT-5 (3.67) across most evaluation dimensions for the heart disease dataset. Compared to the education dataset, both ChatGPT and Gemini showed weaker methodological performance in the healthcare domain. Although all three AI tools produced largely accurate numerical values, ChatGPT and Gemini performed only limited statistical analyses and did not fit a proper regression model for deeper analysis. In contrast, Claude provided a more complete statistical analysis with detailed interpretations and explanations relevant to the heart disease context.

Claude also demonstrated stronger methodological awareness by checking distributional properties and normality assumptions before applying statistical techniques. When assumptions were not fully satisfied, Claude suggested appropriate non-parametric alternatives. ChatGPT and Gemini did not discuss distributions of variables or statistical assumptions in sufficient detail. In addition, both ChatGPT and Gemini introduced a new variable named “heart disease," which was not originally present in the dataset. They attempted to conduct analyses based on this variable. This represents an example of hallucination, where the models generated unsupported information not derived from the dataset.

In terms of interpretive quality, Claude performed better by providing clearer explanations and interpretations related to clinical relevance and the healthcare domain. Compared to the performance in education data analysis, both ChatGPT and Gemini showed weaker performance in healthcare analysis and provided more general interpretations with less meaningful discussion related to the healthcare domain. However, all three models showed a limited discussion on confounding variables and did not sufficiently address their possible impact on the findings. For consistency and reliability, Claude and Gemini produced relatively stable outputs across repeated runs.

Table 12 presents a summary of the comparative performance of three AI models across the education and healthcare datasets. Claude Sonnet 4.6 consistently achieved the highest performance with a mean ARS of 4.84. The very small variability between the two datasets (0.04) indicates that Claude’s performance was highly stable and reliable across different domain contexts. This suggests that Claude not only performs well in individual tasks but also maintains consistent quality regardless of the dataset type.

Table 12. *Summary of the Comparison Results*

Model	ARS of Education Dataset	ARS of Healthcare Dataset	Mean ARS	Standard Deviation
Claude Sonnet 4.6	4.81	4.87	4.84	0.04
ChatGPT GPT-5	4.05	3.67	3.86	0.27
Gemini 3 Flash	4.10	3.88	3.99	0.16

In contrast, ChatGPT GPT-5 showed the lowest overall performance, with a mean of 3.86. Its higher variability (0.27) indicates less reliability and is more sensitive to changes in domain context. Gemini 3 Flash performed slightly better than ChatGPT overall, with a mean ARS of 3.99, but still showed moderate variation between data sets.

Based on the mean ARS values in Table 12, Claude Sonnet 4.6 falls within the 4.5-5.00 range, meaning it is highly reliable and suitable for independent analytical use. In contrast, ChatGPT GPT-5, and Gemini 3 Flash fall in the 3.5-4.49 range, indicating that they are moderately reliable and require human oversight.

Error Taxonomy Results

Table 13 provides the frequency of each error type recorded for Claude Sonnet 4.6, ChatGPT GPT-5, and Gemini 3 Flash during the evaluation process.

Table 13. *Error Taxonomy*

Error Type	Claude Sonnet 4.6	ChatGPT GPT-5	Gemini 3 Flash
Hallucination	0	1	1
Misinterpretation	1	1	1
Omission	0	4	4
Under-contextualization	2	4	4
Total Errors	3	10	10

According to Table 13, Claude Sonnet 4.6 produced the fewest errors overall, with only three errors compared to ten errors each for ChatGPT GPT-5 and Gemini 3 Flash. The most notable hallucination error occurred in the healthcare dataset, where both ChatGPT and Gemini introduced a new variable called *heart disease* that was not present in the original dataset. All three models also made misinterpretation errors in the education dataset by describing a correlation coefficient of approximately 0.5 as a strong linear relationship, when it would generally be considered a moderate relationship.

The largest differences between the models were seen in omission and contextualization errors. Unlike Claude, both ChatGPT and Gemini failed to check important assumptions required for linear regression and significance testing in the education dataset. Furthermore, they failed to fit a linear regression model and to overlook key significance testing assumptions in the healthcare dataset. They further provided less domain-specific discussion, particularly in healthcare analysis since their interpretations were often general and lacked clinical context.

Conclusions

This study evaluated the effectiveness and reliability of AI-assisted statistical analysis by comparing ChatGPT GPT-5, Claude Sonnet 4.6, and Gemini 3 Flash using a structured evaluation framework across education and healthcare datasets. The results showed that all three AI tools were able to provide generally accurate statistical results and useful interpretations. However, there were clear differences in their overall performance. Claude Sonnet 4.6 performed well in both education and healthcare datasets, achieving high scores across statistical accuracy, interpretability, domain appropriateness, limitation awareness, and consistency. Claude earned the highest mean ARS score, which indicates high reliability and appropriateness for analytical applications independent of a user. GPT-5 and Gemini 3 Flash were rated as having moderate reliability and appropriate for use with human oversight. Although both models provided useful analyses, they showed a weakly methodological completeness with less detailed interpretations and sometimes presented unsupported findings.

Limitations

Several limitations should be considered when interpreting the findings of the study. First, the evaluation was limited only to three AI models, and these models were not specifically designed for statistical tasks. Second, the analysis was conducted using only two datasets from the education and healthcare domains. Therefore, these findings may not fully represent the wide variety of data types and analytical scenarios encountered in real-world applications. In addition, the study relied mainly on a single prompt, with only minor modifications used to assess consistency. Different prompt designs may have produced different results. The study also evaluated the models based on initial responses without using follow-up prompts to correct errors, address omissions, or improve interpretations. Therefore, the findings reflect how the models perform in a single-round analysis rather than in an interactive setting where users can refine and guide the analysis.

Future Research

This work can be expanded in the future by considering more AI tools and datasets from additional domains. Different experimental designs could be used to study the impact of prompt engineering, iterative interactions, and feedback-based improvement on the quality of AI-generated statistical analyses. Future studies could also examine model performance on more complex data structures such as time series, hierarchical, and high-dimensional datasets, which require different analytical approaches. Another important direction would be to compare general-purpose AI models such as ChatGPT, Claude, and Gemini with AI tools specifically designed for statistical data analysis tasks such as DataRobot, IBM SPSS Modeler, and Julius AI. Future evaluations may also consider factors such as efficiency of computation, response time, and resource requirements in addition to analytical quality to provide a more complete understanding of the use of AI-assisted statistical analysis in real-world applications.

Overall, this study shows that although AI tools can significantly assist with statistical analysis, they are not yet reliable enough to replace human decision-making. Their effectiveness is mostly dependent on how well-structured prompts are used to guide AI tools and how closely their outputs are examined and analyzed. Human supervision is still important to identify errors, ensure methodological accuracy, and provide appropriate context. These results provide useful information for researchers, educators, and data practitioners on responsible and controlled use of AI in statistical analyses. Further, this study emphasizes the need to treat artificial intelligence in both academic, research, and real-world statistical applications as a supporting tool rather than a fully independent analyst.

Acknowledgments

The author would like to acknowledge the use of artificial intelligence tools in the completion of this study. Since the focus of this research is the reliability of AI-generated interpretations, ChatGPT, Claude AI, and Google Gemini were used as part of the data analysis and comparative evaluation process. These tools were applied to generate statistical outputs and interpretations across models. All AI-generated outputs were carefully reviewed, verified, and critically assessed by the author.

References

American Educational Research Association, American Psychological Association, & National Council on Measurement in Education (2014) *Standards for Educational and Psychological Testing*. American Educational Research Association.

American Psychological Association (2020) *Publication Manual of the American Psychological Association* 7th Edition. American Psychological Association.

Anthropic (2025) *Claude models overview: Sonnet 4.6.* Anthropic PBC.

Bang Y, Cahyawijaya S, Lee N, Dai W, Su D, Wilie B, et al. (2023) A Multitask, Multilingual, Multimodal Evaluation of ChatGPT on Reasoning, Hallucination, and Interactivity. In *Proceedings of the 13th International Joint Conference on Natural Language Processing and the 3rd Conference of the Asia-Pacific Chapter of the Association for Computational Linguistics (Volume 1: Long Papers)* [Nusa Dua, Bali], 675–718.

Bender EM, Gebru T, McMillan-Major A, Shmitchell S (2021) On the dangers of stochastic parrots: Can language models be too big? In *Proceedings of the 2021 ACM FAccT Conference*, 610–623.

BenMessaoud F, Agrebi MH, Ash E (2025) FazBoard: An AI-Educational Hybrid Intelligent Teaching & Learning System. *Athens Journal of Technology & Engineering* 12(1): 29–40.

Bommasani R, Hudson DA, Aditi E, Altman R, Arora S, Kattell S, et al. (2021) *On the opportunities and risks of foundation models*. Stanford Center for Research on Foundation Models.

Chang Y, Wang X, Wang J, et al. (2024) A Survey on Evaluation of Large Language Models. *ACM Transactions on Intelligent Systems and Technology* 15(3): 1–45.

Demir F, Yavuz U (2026) Evaluating the Performance of Generative Artificial Intelligence Models in Multidimensional Data Analysis Tasks: A Comparative Study with Large Language Models. *Discover Computing* 29(1): 20.

Elm E, Altman DG, Egger M, Pocock SJ, Gøtzscheet PC, Vandenbroucke JP (2007) The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: Guidelines for Reporting Observational Studies. *PLOS Medicine* 4(10): e296.

Fehlmann T, Kranich (2025) How to Teach Literacy to Artificial Neural Networks Making AI Intelligent by Learning from Other Disciplines. *Athens Journal of Sciences* 12(1): 59–70.

Field A (2018) *Discovering statistics using IBM SPSS statistics*. 5th Edition. SAGE Publications.

Frieder S, Pinchetti L, Griffiths RR, Salvatori T, Lukasiewicz T, Petersen PC, et al. (2023) Mathematical capabilities of ChatGPT. *Advances in Neural Information Processing Systems* 36.

Google DeepMind (2025) *Gemini model family: Flash.* Google DeepMind.

Guo Z, Jin R, Liu C, Huang Y, Shi D, Supryadi, et al. (2023) *Evaluating Large Language Models: A Comprehensive Survey*. arXiv.

Holmes W, Porayska-Pomsta K, Holstein K, Sutherland E, Baker T, Shum SB, et al. (2022) Ethics of AI in education: Towards a community-wide framework. *International Journal of Artificial Intelligence in Education* 32(Apr): 504–526.

Hong Y, Lian J, Xu L, Min J, Wang Y, Freeman LJ, et al. (2023) Statistical perspectives on reliability of artificial intelligence systems. *Quality Engineering* 35(1): 56–78.

Ji W, Yuan W, Getzen E, Cho K, Jordan MI, Mei S, et al. (2026) *An Overview of Large Language Models for Statisticians*. The American Statistician.

Ji Z, Lee N, Frieske R, Yu T, Su D, Xu Y, et al. (2023) Survey of hallucination in natural language generation. *ACM Computing Surveys* 55(12): 1–38.

Kadavath S, Conerly T, Askell A, Henighan T, Drain D, Perez E, et al. (2022) *Language models (mostly) know what they know*. arXiv.

Kasneci E, Seßler K, Küchemann S, Bannert M, Dementieva D, Fischer F, et al. (2023) ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences* 103(Apr): 102274.

Kavlakoglu C, Stryker E (2024) *What Is Artificial Intelligence (AI)?* IBM.

Keller A (2026) *Expanding the AI Evaluation Toolbox with Statistical Models*. NIST AI NIST AI 800-3, National Institute of Standards and Technology.

Kung TH, Cheatham M, Medenilla A, Sillos C, De Leon L, Elepaño C, et al. (2023). Performance of ChatGPT on USMLE: Potential for AI-assisted medical education using large language models. PLOS Digital Health 2(2): e0000198.

Liang P, Bommasani R, Lee T, Tsipras D, Soylu D. Yasunaga M, et al. (2022) *Holistic evaluation of language models*. arXiv.

Likert R (1932) A technique for the measurement of attitudes. *Archives of Psychology* 22(140): 1–55.

Liu Y, Iter D, Xu Y, Wang S, Xu R, Zhu C (2023) *G-Eval: NLG evaluation using GPT-4 with better human alignment.* arXiv.

Messick S (1989) *Validity*. In RL Linn (eds.), *Educational measurement*. 3rd Edition. New York, NY: American Council on Education/Macmillan.

Nagarkar C, et al. (2026) *Can LLM Reasoning Be Trusted? A Comparative Study: Using Human Benchmarking on Statistical Tasks*. arXiv.

OpenAI (2025) *GPT-5 and ChatGPT capabilities.* OpenAI.

Ouyang L, Wu J, Jiang X, Almeida D, Wainwright C, Mishkin P, et al. (2022) Training language models to follow instructions with human feedback. *Advances in Neural Information Processing Systems* 35: 27730–27744.

Pearl J, Mackenzie D (2018) *The book of why: The new science of cause and effect.* Basic Books.

Peters U, Chin-Yee B (2025) Generalization Bias in Large Language Model Summarization of Scientific Research. *Royal Society Open Science* 12(4): 241776.

Redwan K (n.d.) *UCI heart disease data*. Kaggle. https://www.kaggle.com/datasets/redwankarimsony/heart-disease-data (Accessed March 21, 2026).

Shen T, Jin R, Huang Y, Liu C, Dong W, Guo Z, et al. (2023). *Large language model alignment: A survey*. arXiv.

Slobodsky P, et al. If You Can't Beat It, Join It! Teaching and Learning Mathematics with ChatGPT and Key Prompts to Stimulate Self-Learning. *Athens Journal of Education* 13(1): 185.

Sonawane S (n.d.) *Student performance dataset*. Kaggle. https://www.kaggle.com/datasets/suvidyasonawane/student-performance-dataset (Accessed March 18, 2026).

Stryker C (2021) *What Are Large Language Models (LLMs)?* IBM.

Thirunavukarasu AJ, Ting DSJ, Elangovan K, Gutierrez L, Tan TF, Ting DSW (2023) Large language models in medicine. *Nature Medicine* 29(Jul): 1930–1940.

Xiao T, Zhu J (2025) *Foundations of Large Language Models*. ArXiv.

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Community Engagement in Cybersecurity, Pervasive Computing and Democratic Use of CYb

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Community engagement practices can support effective cybersecurity and promote public safety and security. The foundations of Democratic Cybersecurity promote effective competent and safe use of computing systems across society and to all of its people. A failure to introduce general competencies with fundamental security principles of cyber systems increases the risk of damage to their effectiveness and potential injuries that may result from cyber system breach. We consider the means to mitigate these risks, and examine models for such action, in the contexts of the United States and the Republic of Kosovo and detail successful frameworks for implementation by all communities.

Keywords: *community, engagement, democracy, cybersecurity*

Introduction

Research Question: Can community engagement and the involvement of citizens in cyber security practices strengthen democratic cybersecurity in a world of growing threats and pervasive computing?

Integration of workforce education, criminal justice, and computer engineering applications can effectively establish better cybersecurity as a community-driven effort. Interrogating current programs and practices permits an identification of successful and replicable frameworks and propose innovative pathways for future development with a public cyber safety focus. Key initiatives include pioneering collaborations with a variety of groups to enhance cybersecurity education and training pipelines. It is vital to emphasize the role of workforce development in preparing skilled professionals, criminal justice frameworks of public integrity and safety, and engineering perspectives in designing resilient systems and practical solutions. These collaborations begin by outlining strategies for implementation, evaluation frameworks, and the potential for future programs, aiming to inspire interdisciplinary approaches and actionable solutions for strengthening national cyber defense and resilience.

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Literature Review

Buckland et al. (2015) analyzed the special challenges of trans-border cybersecurity and the democratic governance concerns in addressing this:

> Cyber security encompasses borderless challenges, while responses remain overwhelmingly national in scope and even these are insufficient. There are enormous gaps in both our understanding of the issue, as well as in the technical and governance capabilities required to confront it. Furthermore, democratic governance concerns – particularly regarding control, oversight and transparency – have been almost entirely absent from the debate. These concerns are exacerbated by the enormous role played by private actors (both alone and in cooperation with governments) in online security of all types. Given the pace at which states and private companies are reinforcing online security and preparing for cyber war, addressing democratic governance concerns has never been more pressing (Buckland et al. 2015, p. 7).

Ismail et al. (2024) surveyed cybersecurity activities in education and curriculum design, noting the challenge in workforce development for cybersecurity; they found a variety of challenges for educational institutions when designing effective cybersecurity activities and curriculum. Earlier estimates found as many as 1.8 million vacancies in cybersecurity-related positions in the United States along (Alhamdani 2019, Morgan 2015). They focused their surveys on needs within pre-university and university training, including training for teachers in those domains; this ranged from high-level technical skills to cybersecurity awareness and education campaigns. The latter includes the "Stop.Think.Connect" training where "This online awareness and education campaign emphasizes that cybersecurity is a shared responsibility for all who benefit from cyberspace. It encourages everyone to take a moment to stop and think about the potential threats in cyberspace."

Such expansive initiatives are supported by the National Initiative for Cybersecurity Education supporting education and training across all levels (Crabb et al. 2024). This mirrors similar initiatives such as that of the UK, "National Planning Policy Framework (2011)[1]. The "UK Cyber Security Strategy Protecting and promoting the UK in a digital world,"[2] emphasized the importance of this, directing that the UK "…conduct research on how to improve educational involvement with cyber security significantly at all levels – including higher education and postgraduate level." But this also includes a focus on prevention and public awareness, including "Look at the best ways to improve cyber security education at all levels so that people are better equipped to use cyberspace safely." In this the UK government partnered with private technology companies such as Microsoft and Symantec and major commercial operations such as HSBC ad Paypal.

Kerrick et al. (2024), Losavio (2025), Losavio et al. (2022) have argued for the need of a new way of approaching cybersecurity and cybersecurity skills through a "democratic" model that directly engages people engaged with such systems. They

[1]Department for Communities and Local Government. *Draft National Planning Policy Framework: Consultation*. July 2011. GOV.UK.

[2]Department for Communities and Local Government. *Draft National Planning Policy Framework: Consultation*. July 2011. GOV.UK.

note the effectiveness of the Cybersecurity Academic Excellence certification program for promoting this:

> The United States needs a new paradigm in the development of cybersecurity knowledge and skills, one that democratizes them for all people. The Cybersecurity Academic Excellence (CAE) model is one effective foundation that can be expanded to accomplish this democratized effect for a distributed model of cybersecurity. Options for this expansion use cybersecurity teaching projects across multiple domains include workforce skills training. Those domains range from computer science, engineering, human development and learning, and law enforcement, integrating the fundamental computing skills curricula of both middle and high schools as well as postsecondary studies in non-computing areas, from psychology to the humanities. This integrated approach is the essence of democratic cybersecurity.

This has been implemented and tested at several levels and disciplines, including:

1) Health care professionals.
2) Military staff and families.
3) Law enforcement officers.

These reflect the need argued by Grzegorzewski et al. (2023) that in a world of ubiquitous connections cybersecurity, as everyone's responsibility, needs a whole-of-society approach in cybersecurity, as detailed in their "Civil Cyber Defense - A New Model for Cyber Civic Engagement."

Similarly, Powazek and Menna (2025) argue this is needed if cybersecurity is to be sufficiently effective, that a "co-responsibility model" for cybersecurity detailing responsibilities of communities and special actors.

There is broad sentiment that the means by which any community or any nation approaches cyber security must include all of the Community. In the United States there is grown support for expanding cyber security skills in more and more disciplines to more and more people. This ranges from law enforcement and health care professionals to teachers, students and their families.

Methodology & Prior Work

We must consider the needed elements for an outline of a program for a basic cybersecurity program of four to five courses to promote democratic cyber security that are achievable in a reasonable period of time. A practical cybersecurity program should provide basic computing, programming and cybersecurity skills needed for the modern workplace, as well as in the home. For criminal justice in particular, this knowledge is essential for democratic cybersecurity for the United States and other countries, such as Kosovo[3].

[3]The University of Louisville has been very successful in securing grants for cybersecurity training for various cadres, from military to law enforcement. The Kosovo Academy for Public Safety has secured access to instructors for its police officers in these cybersecurity areas.

The research methodology to be used begins with an examination of prior and current programs for distributed, democratic cyber security, identifying key elements of each and conception of future models for implementation and testing.

That examination indicates that a fundamental course program addresses that need can be designed and implemented. Should students wish to go further in these studies, these courses map to curriculum in computer science departments such as those in science, engineering and mathematics departments[4]. There are similar curricula in other parts of colleges such as the business school.

Those five fundamental three-hour courses are:

1. Cyber Fundamentals – This course covers core computing and cybersecurity terminology and concepts and discusses current challenges and threats faced by individuals, organizations, and nations using current topics, case studies, and hands-on labs.
2. Cyber Applications - This course covers core computing skills for the workplace, from standard work applications to basic scripting and programming.
3. Programming Languages - This course introduces programming logic and constructs in Python and basic command line scripting in Linux and Windows environments. Arithmetic operators, logical operators, functions, classes/objects and other elements are covered in Python with possible examination of C++ and R.
4. Cybersecurity Fundamentals - This course covers and expands on core cyber security terminology, concepts, and challenges through case studies and discussions. Application to government, commercial and consumer environments will be a focus with hands-on exercises in areas such as network/device security hygiene, search techniques, incident response, and risk assessment.
5. Digital Forensics and Crimes Involving Computing - This course teaches students how to prepare for incidents, how to respond to incidents and investigate them, and how to reliably collect digital data and evidence from various types of storage media and sources of volatile data.

University of Louisville Computer Science Students - One Effort at Implementation that Incorporates These Elements

Any such implementation requires evaluation and systematization and should include a culminating experience/community engagement component relating to computing skills and services relating to less technically advantaged populations, such as handicapped, refugees, juveniles, low-income or senior citizen communities. It must review and evaluate the benefit to learners and the community of current *ad hoc* community engagement components in computer science and computer engineering departments and discuss ways to systematically continue and promote these components.

Under a program in the department of computer science and engineering of the Speed Engineering School of the University of Louisville, over the course of a Fall or Spring semester, students trained and mentored community residents in a variety of computing and cybersecurity skills. The learners included students at Simmons College,

[4]https://catalog.louisville.edu/undergraduate/minors/computer-science-minor/.

the senior citizens of the Portland Plaza HUD senior citizens facility in the Portland neighborhood and individuals, some elderly or with disabilities, of a New Directions Housing St. William's center, to access the Internet for communication, information, socialization and communication services.

Computer science students worked with community members on skills and practices for the effective and safe use of the Internet for a variety of services. It presented students with the human factor in computing and issues of how to overcome some of the limitations on the use of computing by segments of the population. The effective and safe use of search was a key skill, along with the effective and safe use of email in the increasingly treacherous online environment. Connection with family was especially important; internet telephony applications allowed the learners to communicate with family all across the country and world without extra fees, a particular burden for people on fixed incomes.

The students generally found the experience worthwhile; the work connected their advanced skills back to individuals who may be using the technology, particularly those with minimal skills with digital technology. Those skills ranged from safe operation of computing and internet systems to technical development to make systems operational for the learners, such as writing device drivers for systems and installation and implementation of new wireless networks.

The people trained were appreciative of the help, especially in areas they were unable to address due to their lack of knowledge or skill. This was a particular issue for elderly and handicapped individuals with no prior experience with these systems. A hallmark case was setting up teleconferencing software to let them connect with family members despite having poor transportation options. The benefits of teleconferencing included connecting with family members in the military who were stationed abroad, but even applied to family members located elsewhere in the state and country.

The program was operational for over fifteen years, with hundreds of students and community members benefiting from it. Once the course was moved online it became more difficult to operate and the community projects ended in 2024.

Kosovo Academy for Public Safety - Evaluating Transnational Applications of Community Engaged Cybersecurity in Kosovo

The Kosovo Academy for Public Safety (KAPS) began a project to develop cybersecurity training of law enforcement in 2019. This project aimed to develop a cybersecurity shield against IT threats to law enforcement and security of the nation of Kosovo, threats both internal and external. The primary challenge was lack of knowledge and awareness of cybersecurity by its local law enforcement. That would be remediated by cybersecurity training at multiple levels. These skills would also serve to prepare law enforcement for investigation and prosecution of cybercrime perpetrators.

The objectives of this project as set out in the proposal were:

1. To develop a cyber security capacity for Kosovo law enforcement agencies, including police, customs, corrections, probation, police inspectorate, and emergency management.

2. To develop a cyber security certificate program for professionals working in the law enforcement and IT security fields to train them in protection and mitigation of cyber-security crimes.
3. To offer seminars and workshops to law enforcement to make them aware of the dangers of cybercrimes and provide them knowledge to protect themselves and their agencies.

KAPS asked for the assistance of University of Louisville faculty to visit the academy for two-week periods to develop these objectives through planning, implementation and evaluation. This visit was supported by the US Embassy and via the Fulbright Specialist program administered by World Learning, a State Department contractor. These two-week periods would be separated by 4 to 6 month implementation periods by Academy personnel. These implementation periods and new visits by the specialists would permit development and training of law enforcement on cybersecurity, evaluation of the training and expansion of train-the-trainer programming for new instructors and overview programming for new audiences in the Public Safety and security community.

1) Academy Working Group, Prior Work, Project Outcomes

The KAPS working group for the cybersecurity project consisted of:

Shaban Bajrami, Acting Director of Department for Training and Educational Support
Abaz Ahmeti, Head of Training Division
Sami Zeka, Director of Department of Information Technology
Avni Istrefi, Head of International and External Relations
Mirnje Mernica, interpreter for the group
Skender Agaj of External Relations and
Muhamed Gerxhaliu, an IT consultant and instructor at Rochester Institute of Technology/American University of Kosovo volunteering on the project and providing technical support and guidance on the project.

The working group was supported in its efforts by Kastriot Jashari, director of KAPS and Emin Uka, head of Quality Assurance/Accreditation for KAPS[5]. An outline of the course modules, objectives and topics and bibliography was developed to guide curriculum development; it considered, *inter alia*, of lesson plans for legal and computer forensic modules, review of IT basics, information security and network security modules.

The Academy structured its curriculum development on contemporary adult learning principles and formats. These formats progressed from topics to learning objectives, directed content, and finally training techniques in order to engage all learners across multiple learning modalities. The course outlines required delineation of:

[5]KAPS is accredited by the International Association of Directors of Standards and Law Enforcement Training (IADLEST) of the United States of America, which is supported by the US Bureau of Justice Assistance of the US Department of Justice (See https://www.iadlest.org/, accessed 18 December 2022).

1. Lesson duration
2. Means of concretization/presentation
3. Lesson goal
4. Lesson objectives
5. Introduction to the lesson
6. Delineation of each lesson objective with bibliography
7. Exercises, particularly those requiring hands-on engagement of the learner
8. Culminating Project/Exam for Assessment of the learner
9. Lesson summary
10. Reference materials
11. Appendices

Prior work on cybersecurity training for local law enforcement in the United States was reviewed with the working group. Based on this, a needs assessment survey for Kosovo law enforcement was developed and will be distributed. A preliminary set of topics based on the US experience was settled upon and used to design course plans for each of those topics based on the adult learning models of the academy.

The preliminary topics for the courses/course outlines for the basic series were:

- IT fundamentals
- Information Security
- Network Security
- Computer Forensics
- Legal/Ethical issues

Draft course outlines and lesson plans for all five Basic topic areas were completed by the University of Louisville faculty and Muhamed Gerxhaliu, the instructor at Rochester Institute of Technology/American University of Kosovo. Mr. Gerxhaliu of RIT/AUK provided key support for the project, including development of course plans in IT Basics, information security and network security. Funding to hire instructors, possibly including Mr. Gerxhaliu and his fellow instructors at RIT, would assure continuity of teaching in these areas.

Sami Zeka, the director of IT for KAPS, configured a 30 seat computer laboratory to serve as a teaching space for the law enforcement learners. Challenges may include access to the appropriate teaching and analysis software beyond open source materials.

An exemplar of the draft course for Computer Forensics/*Forenzika Kompjuterike* and an exemplar of the draft course for Legal Issues with Cyber Security/*Çështjet ligjore me siguri kibernetike* were completed for use and guidance.

The working group planned to continue with course development with cybersecurity, subject to resources. This included development of advanced courses in cybersecurity and digital forensics. Access to industry-standard training resources would be helpful, although not budgeted for at this time.

2) *KAPS Orientation and Assessment*

As part of an orientation program, University of Louisville faculty gave a series of presentations on the results of US efforts in this area of cybersecurity for local law enforcement. The project included a series of seated and online presentations on the prior work and outcomes for law enforcement cybersecurity training. These provided overviews of training, cybersecurity modules and materials by University of Louisville faculty.

Dr. Cheryl Purdy discussed teaching Computer Forensics and IT Basics. Dr. Purdy teaches at several colleges on issues and practices relating to computer and digital forensics. As a sworn deputy sheriff, she testifies on digital evidence in criminal prosecutions. Computer engineering professor Dr. Adrian Lauf presented on Information Security, Network Security and the construction of virtual cybersecurity laboratory environments using ProxMox on secure multi-processor cluster[6]. The head of the University's Office of Industry Research and Innovation, Dr. Adel Elmaghraby, presented on the development and implementation of a comprehensive cybersecurity discipline in the organization. Topics covered included collaboration with industry and the academy, from training to advanced research projects. Criminal Justice department chair Dr. Thomas Hughes discussed the creation and implementation of law enforcement training and academic teaching programs geared towards managing innovation and changing policing. This discussion included resources offered through the University's Southern Police Institute (https://louisville.edu/spi) and the Department of Criminal Justice (https://louisville.edu/justice).

Additional online presentations by University of Louisville personnel working in this space are being developed. Presenters may include Dr. Jeff Sun and Dr. Sharon Kerrick of the College of Education and principal investigators on two IT cybersecurity training initiatives, and Mr. Mike Bassi, director, and Dennis Hippert, deputy director, of the Southern Police Institute of the University of Louisville.

An overview of training for prosecutors on cybersecurity and work with law enforcement was also presented. This would aid in the coordination between police and prosecutors on cybercrime investigations. This may be particularly important under civil law regimes where that coordination is more extensive than under the Anglo-American model.

3) *KAPS Beta Test Cohort*

At the end of the two-week project closing Beta presentations on cybersecurity were done for about 30 Kosovar students of the Kosovo Academy for Public Safety from criminal law and psychology classes. These learners ranged in police rank from lieutenant to patrol officer and were assigned to intelligence, analysis, patrol and investigation. The group included correctional officers and a customs/immigration officer. Their studies were advanced beyond primary officer training and directed towards degrees in the bachelor's program of the Academy.

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[6]See https://engineering.louisville.edu/faculty/adrian-p-lauf/.

The presentations were disrupted towards the end due to outbreaks of communal violence; about half the class were call back to duty to address this.

Almost uniformly they were deeply engaged in the sessions, including discussion on outreach to communities to improve cybersecurity. There was a special concern for the cyber-safety of the elderly and the safety and habits of juveniles in this area. The officers opined that this was training of value to them.

The consensus for these officers was that this training is needed by Kosovo law enforcement, and the citizens of their republic, with a special concern about juveniles and their actions online.

Discussion

The participating students and learners agreed that the training was beneficial to them and their communities. Even as presenting new technical skill areas outside of traditional law enforcement training, the learners found them valuable when mapped to contemporary conditions. Those conditions found in public security and community life of the hyperconnected world of ubiquitous and pervasive computing presented new areas of vulnerability for the peoples of the community.

The need for such security for computing is seen in the repeated, effective attacks on cyber resources in all domains. It is particularly critical with the expansion of cyber systems to all areas of society. A "democratic" cybersecurity regime addresses that pervasive risk.

College and Community

The need for pervasive cyber security for pervasive computing offers useful and important engagement in the community to devise and implement the needed skills. These skills range from the technical to the personal importance of individuals acting safely with computing. The collegiate student community cybersecurity trainings by computer science and engineering students were of benefit to both the students and the community members.

For the students it was an introduction, re-introduction and reminder of the human-centered elements in effective and secure computational systems that directly interface with members of the community. For the community members it offered access to computing technologies and the knowledge for safe, competent use to which they had little or no prior exposure. This opened to them the connection to a wider world that enriched their lives, with knowledge of some of the dangers involved and the means to avoid those dangers.

Kosovo Academy for Public Safety

The Kosovo Academy for Public Safety (KAPS) began its project to develop cybersecurity training of law enforcement in 2019. Delayed by the COVID-19 pandemic, recruitment of expert support began in Fall, 2022. The supporting University of Louisville faculty visited for two weeks in November – December, 2022, in person and online, with the KAPS working group. That working group developed an outline of the curriculum; a set of course plans for IT fundamentals, Information Security, Network Security, Computer Forensics and Legal/Ethical issues, that served as the foundation for the project.

The progress on this project in a very short time was remarkable. The Kosovo working group accomplished far more in that short time than anticipated, creating a foundation to quickly implement training and assess the outcomes. The preliminary beta test of the course material with a heterogeneous group of law enforcement indicates that this is both needed and would be welcomed. These findings should be interested with caution as these learners are a self-selected group of law enforcement officers seeking to advance their education and training beyond that needed for their positions As such they may be especially predisposed towards new learning in advanced areas.

Nonetheless, in both the significant progress made by the staff and positive response from the learning group of law enforcement officers, this project demonstrates a great deal of potential to improve the current and future safety of the people of Kosovo.

Comparison of College/Community and KAPS

Although each project had distinct training groups and professions, with different target beneficiaries, they both shared common outcomes:

1) Both groups, college computer engineering students and state/local law enforcement personnel, found the training of value for themselves and their respective professions.
2) Both groups noted the needed benefits for the people of their communities.

    a. For the college students it related back to their ethical and social obligations for good and safe computing, including their awareness of the needed for systems to reflect the skill level of the target users.
    b. For the law enforcement officers it related to their general goal of protecting their civilian populations and then to specific problems they had seen during law enforcement protection and investigation actions, especially as to juveniles.

3) Both groups supported continuing such training and community engagement relating to computing for the benefit of their professions and their communities.
4) Completion rates were 100% for both groups, although for the learners this was due primarily due this participation of the students/learners being required; community participants also generally completed their sessions, motivated by the value of the new topic they were being taught.

Community engagement beyond classroom learning correlates with improved success rates in the cyber security cohorts. This may be due to overall special components of community engagement. It may also be due to the special value community-based learning offers in connecting learning to immediate, practical and tangible benefits for both the learners and the community benefited.

First, by making learning immediately relevant to agreed goals, particularly the protection and security of people, the students realize their success is more than academic exercises but work that directly impacts people. They become responsible for more than just their grade assessment but also for the safety and wellbeing of others.

Second, this demonstrates that the complexity of human-cyber interactions must be considered, not just the solution of a technical problem. Goal-oriented students want to succeed and meet the goal; showing that complexity lets them know all they must address to succeed with an effective cyber security situation.

Lastly, the messiness of many human situations, especially as to cyber security, has become a valuable teaching and learning tool for successful implementation of any effective computing system beyond academic exercises. It demonstrates the need for cyber security and any functional analysis to expand well beyond immediate technical issues to embrace those messy and complex conditions – technical and social- and address them before people, possibly many people, are hurt. The injuries from the disruption of the security of people's homes, health, finances and families can be immense where those lives are touched by cyber systems.

Conclusion

These models serve as templates of means to promote greater effective cybersecurity throughout society. They are hallmarks of "democratic cybersecurity" where the practices and skills needed for secure computing are distributed along all tiers of society. These foundational lessons in cybersecurity should be portable across all jurisdictions, particularly due to common engineering elements in operating systems and the Internet and common use elements and vulnerabilities across cyber systems.

There is a critical general distributed need for such cyber security skills in our diverse communities as all embrace pervasive computing. A cyber-attack against Kosovo's neighbor Albania by the Islamic Republic of Iran is a harbinger of dangers to come.

The college students' and Kosovo law enforcement's efforts in expanding cybersecurity through traditional public security helped their communities. They can guide others in the protection of people in our ubiquitous, pervasive computing world. And that protection is sorely needed.

Acknowledgments

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References

Alhamdani WA (2019) Adopting the cybersecurity curriculum guidelines to develop a secondary and primary academic discipline in cybersecurity postsecondary education. *Journal of Cybersecurity Education, Research and Practice* 2019(1): 2.

Buckland B, Schreier F, Winkler T (2015) *Democratic Governance Challenges of Cyber Security*. DCAF HORIZON 2015 Working Paper. Available at: https://www.dcaf.ch/sites/default/files/publications/documents/CyberPaper_3.6.pdf.

Crabb J, Hundhausen C, Gebremedhin A (2024) A Critical Review of Cybersecurity Education in the United States. In *Proceedings of the 55th ACM Technical Symposium on Computer Science Education,* volume 1, 241–247.

Grzegorzewski G, Smith M, Koven B (2023) Civil Cyber Defense – A New Model for Cyber Civic Engagement. *The Cyber Defense Review* 8(3): 51–66.

Ismail M, Thorakkattu Madathil N, Alalawi M, Alrabaee S, Al Bataineh M, Melhem S, et al. (2024) Cybersecurity activities for education and curriculum design: A survey. *Computers in Human Behavior Reports* 16(Dec): 100501.

Kerrick SA, Sun JC, Elmaghraby A, Losavio MM (2024) CAE Models for the Expansion of Cybersecurity Knowledge in the U.S. *Technology Interface International Journal* 25(1): 34–39.

Losavio MM (2025) Security and Privacy in Ambient Intelligence, the Internet of Things and Pervasive Systems: Interrelationships for Systems of Public Safety. In *Future of Information and Communication Conference*, 678–687. Cham: Springer Nature Switzerland.

Losavio M, Sun JC, Kerrick S, Elmaghraby A, Purdy C, Johnson C (2022) Integrating democratic cybersecurity: Empowerment of traditional law enforcement and democratic public safety. In RP Griffin, U Tatar, B Yankson (eds.), *17th international yearbook on cyber warfare and security*. Academic Conferences International, Ltd.

Morgan S (2015) Cybersecurity job market to suffer severe workforce shortage. *CSO Online* 28.

Powazek S, Menna G (2025) *The Roadmap to Community Cyber Defense: A Path Forward from the Cyber Resilience Corps*. Available at: https://cltc.berkeley.edu/publication/roadmap-to-community-cybersecurity/.

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Analysis of the Relationship between AI Advancement and Employment Dynamics in Canadian Higher Education

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The study focuses on the employment dynamics and higher education in Canada. AI technologies have been one of the most important drivers for employment growth, but it should be discussed whether AI advancements also increase the unemployment rate. Additionally, AI technologies are positively utilized by postsecondary education institutes, but whether the AI advancements can also impact the lower-income families on higher education remains discussed. This study primarily employs secondary data, leveraging existing datasets to evaluate four hypotheses. For the classification task, a Random Forest algorithm was selected as the main predictive modeling approach. Our results suggest that AI has slightly restricted access to higher education for low-income students, but is unlikely to have a significant contribution to job replacement within Canadian universities, and our results can be also used to explore longitudinal data on AI's impact on education and employment, assess how AI-driven policies shape long term workforce trends, and examine the ethical considerations surrounding AI deployment in academia.

Keywords: *artificial ıntelligence, higher education, employment in Canada, job replacement, low-income family*

Introduction

Employment trends serve as a crucial indicator of economic stability and growth. The integration of artificial intelligence (AI) into labor markets has introduced both opportunities and challenges. According to Damioli et al. (2024), AI technologies have emerged as significant drivers of employment growth, contributing to increased productivity and the creation of new job sectors. However, these optimistic projections contrast with recent labor market statistics. In 2024, the unemployment rate in Canada rose to 6.1%, marking a 0.3 percentage point increase from the previous year (Thanthong-Knight 2024). This discrepancy raises critical concerns regarding the nuanced effects of AI on employment dynamics, particularly the potential displacement of workers in certain industries.

Given these contrasting perspectives, a comprehensive analysis of AI's role in the Canadian labor market is necessary. This study aims to examine the overall impact of AI advancement on the structure and accessibility of higher education in Canada, with particular attention to its implications for equity, institutional dynamics, and employment outcomes. Rather than treating these issues independently, the study adopts an integrated perspective in which funding

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patterns, student accessibility, academic integrity, and employment dynamics are considered as interconnected dimensions of a broader systemic transformation driven by AI. The research will explore whether government-driven AI initiatives foster job creation or contribute to labor market disruptions, particularly within Canadian universities and research institutions.

Literature Review

AI's role in education has garnered significant scholarly attention, particularly in its potential to enhance learning accessibility. According to Osorio et al. (2024), AI-driven educational tools can accommodate diverse learning needs, providing personalized learning experiences that improve student engagement and academic outcomes. However, the socioeconomic implications of AI in higher education remain a subject of debate, particularly concerning whether AI-driven advancements equitably serve different income groups.

From a socioeconomic perspective, assessing whether AI benefits all students equally or exacerbates existing educational inequalities is crucial. One critical aspect of this discussion is the accessibility of higher education for low-income families. According to Innovation, Science and Economic Development Canada (2024), the national poverty rate stood at 9.9% in 2022, indicating that 3.8 million Canadians lived below the poverty line. This raises the question of whether AI-driven educational technologies provide meaningful opportunities for low-income students or if financial and digital access barriers limit their effectiveness. This study will investigate how AI influences post-secondary education accessibility, particularly for financially disadvantaged students. It will analyze whether AI-based education solutions, such as automated learning platforms, AI-assisted tutoring, and adaptive learning technologies, contribute to reducing or reinforcing disparities in higher education.

There are two foundational perspectives when discussing inequalities: inequality of outcome and opportunity (Danaher 2024). Jonathan et al. (2023) highlight that the advancement of AI has inadvertently perpetuated biased datasets, resulting in unequal outcomes such as exclusion, racism, and gender inequality, which can have adverse effects on human health. In addition, the advancement of AI tools also leads to inequality in opportunities, including accessibility to education, and resource allocation (Danaher 2024).

These inequalities mainly represent four biases, including model design rooted in feature selection, model training and predicting, model deploying, and model evaluating (Chung & Freedman 2024). For example, the feature may tend to high-income groups and jurisdictions rather than minority groups and regions. In addition, the model training and predicting biases are mainly from the skewed model training, including the biases of certain genders and economic groups, leading to unequal outcome predictions (Chung & Freedman 2024). Moreover, the model deploying biases mainly relates to accessibility (Chung & Freedman 2024). For example, the AI model may preferably be deployed in urban rather than rural areas. Finally, the model evaluating biases happens if the evaluation metrics are mainly for specific needs in different groups (Chung &

Freedman 2024). For example, suppose the higher accuracy mainly shows the high-income groups and urban areas. In that case, the biases are generated because this evaluation metric is under consideration of the middle-class group, which also leads to poor performance.

Regarding the implications of AI-driven inequalities for higher education, biased datasets increasingly influence university admissions processes, as many institutions now rely on AI-based tools to evaluate and select candidates globally. The use of biased data can result in systematic mismatches between students and institutions, reinforcing existing inequalities within higher education systems (Austin et al. 2023). Furthermore, advancements in AI have shifted labor-market demand toward AI-related occupations, creating enhanced career opportunities for graduates with training in AI and related fields (Wong 2024). Conversely, this shift may reduce employment prospects for graduates from disciplines such as literature and other non-technical fields, thereby widening disparities across academic domains (Wong 2024).

Teaching is a profound learning experience, embodying the inherent connection between teaching and learning. With the advancement of AI, this connection can be deepened considerably and enhanced. AI can analyze learners' individual needs and tailor teaching strategies to cultivate their growth better (Jamie & Barry 2024). In addition, AI tools can greatly improve accessibility for learners with disabilities (Bressane et al. 2024).

However, the integration of AI in teaching and learning comes with its challenges. A study by Ivanov (2023), highlights that learners' overreliance on AI tools for completing assignments has compelled educators to re-evaluate their assessment methods, often diverting focus from developing personalized teaching strategies (Ivanov 2023). The excessive use of individualized teaching materials to meet learners' needs may also limit learners' exposure to course content, meaning that learners spend less time on exposure to topics (Ivanov 2023). Moreover, AI-based learning and teaching lack emotional and interpersonal interaction (Vistorte et al. 2024). Specifically, AI tools are unable to provide empathy, motivation, and inspiration, which can diminish the passion and energy of both learners and educators. Finally, an overreliance on AI tools can stifle creativity. Students may focus solely on finding ready-made answers rather than engaging in critical thinking, while instructors may only produce AI-generated content instead of thoughtfully designing materials tailored to students' needs (Habib et al. 2024).

Although AI tools can help researchers in higher education during the whole stage of the research process, these tools also mislead researchers to produce incorrect content, and the loss of research abilities for researchers gradually happens in the long run (Ivanov 2023). Additionally, applying AI tools in Academic Research forces research publications to launch stricter publication rules because academic research output may be recognized as not an intellectual contribution (Ivanov 2023).

Research evaluation also plays a vital role in educational practices. Compared to traditional research evaluations, including peer review, citation analysis, and institutional metrics, the research evaluations based on AI advancement mainly use AI tools, such as natural language processing, to optimize those three traditional research evaluations. Although AI tools increase the effectiveness of research evaluations, there is massive room for improvement in assessment because of insufficient, low-quality, and biased datasets due to inaccurate evaluations.

Moreover, AI models, such as natural language processing and machine learning algorithms, are widely used in the student admission process to higher education generating an effective and efficient administrative environment (Raman 2024). Specifically, machine learning models can significantly ease the decision-making process in university admissions. These predictive models can analyze historical data to help universities assess the likelihood of candidates successfully receiving offers. Finally, big AI models, such as Natural Language Processing (NLP), can help students navigate admission by reducing language barriers worldwide.

However, there are many concerns when proceeding with AI for student admissions, such as ethical considerations, student data privacy, and biases and fairness, impacting the decision-making process (Raman 2024). Specifically, the biases or discriminations in AI models exist if the previous admissions limited certain groups, including gender, race, jurisdiction, and so forth. In this case, equity, diversity, and inclusion cannot be ensured unless the admission policies require them. Finally, data privacy risks may exist when institutions misuse personal data or reduce the data transparency for their admission.

AI tools can enhance the efficiency of academic tasks performed by lecturers, including assessment, grading procedures, and reduction of the administrative burden, but AI algorithms can gradually achieve this work, which causes the job replacement of administrators and lecturers (Elizabeth 2024). Specifically, AI tools may replace certain administrative roles where job functions are highly repetitive, such as customer service tasks that can be automated through AI-powered chatbots. In addition, AI tools can perform document verification tasks more efficiently and accurately, reducing the need for manual administrative labor. Finally, instructors may face increasing concerns about job replacement as AI systems become more capable of delivering personalized content, providing feedback, and supporting student learning independently. In this case, AI advancements can provide tailored content and individual feedback for learners, which increases their learning efficiency. However, because students continue to value in-person interaction, mentorship, and discussion with professors, widespread job displacement in higher education is not rapidly happening. Nevertheless, concerns remain that AI tools may increasingly assume educational work that have traditionally been performed by academic staff (Elizabeth 2024).

Table 1 (Statista 2023a, b) presents a global overview of AI adoption across industries and functional areas. The findings indicate that, relative to other sectors, organizations in business, legal, and professional services primarily adopt AI for manufacturing and supply chain management. In the consumer goods and retail sector, AI is predominantly applied to human resources, service operations, strategy and corporate finance, and supply chain management. Within financial services, AI adoption is concentrated in product and service development, service operations, strategy, and corporate finance. In the healthcare and pharmaceutical sectors, AI is mainly utilized for human resources and risk management functions. Similarly, in high-technology and telecommunications industries, AI adoption is largely focused on risk management, service operations, strategy, and corporate finance.

Table 1. *AI Adoption Rate (%) Worldwide 2022 by Industry and Function (Statista 2023a, b)*

Characteristic	Human resources	Manufacturing	Marketing & sales	Product/service development
All industries	11	8	5	10
Business, legal, and professional services	11	10	9	8
Consumer goods/retail	14	4	3	4
Financial services	1	8	7	31
Healthcare/pharma	15	7	2	4
High tech/telecom	6	6	4	7
Characteristic Supply	Risk	Service operations	Strategy & corporate finance	chain management
All industries	19	19	21	9
Business, legal, and professional services	16	20	19	12
Consumer goods/retail	15	31	29	11
Financial services	17	24	23	2
Healthcare/pharma	22	12	8	8
High tech/telecom	38	21	25	8

Methodology

This study primarily employs the quantitative research methodology to explore the hypotheses we defined for this research and the correlation between the use of AI and higher education as well as employment dynamics in Canada. The feature selection process in this study was primarily theory-driven and constrained by the limited availability of longitudinal public datasets related to AI, higher education, and employment dynamics in Canada. Rather than relying solely on automated statistical feature selection techniques, variables were selected based on their conceptual relevance to the proposed hypotheses, consistency with the literature, policy significance, and availability of comparable annual observations across the study period. This approach is consistent with exploratory policy-oriented research, where interpretability and theoretical grounding are prioritized over predictive optimization. Consequently, the selected features should be interpreted as representative indicators of broader structural trends rather than exhaustive predictors of AI's societal impact.

A Machine-Learning based data research design is used to analyze and predict whether AI has a negative impact on higher education in Canada through eight relevant features, including funds allocation to AI by the Federal Government, fund allocation to education by the Federal Government, undergraduate tuition fees for Canadian citizens, number of students enrolled in post-secondary institutions, number of people with low income, number of cases of data violation due to AI in Education, number of studies on academic misconduct due to AI, and whether misuse of AI on academic dishonesty in Higher Education.

Analysis of Variance (ANOVA) was employed to test the statistical significance of differences in mean values across groups or relationships between variables corresponding to each hypothesis. ANOVA is appropriate in this study because the research aims to evaluate whether variations in key predictors (e.g., AI funding, income levels, tuition fees) are associated with statistically significant differences in outcome variables (e.g., employment dynamics, accessibility to education, enrolment levels).

Compared to simple correlation analysis, ANOVA enables formal hypothesis testing by partitioning total variance into explained and unexplained components, making it suitable for evaluating group-based and regression-based relationships within small-sample policy datasets.

Data Collection

Tables 2-3 show that the secondary data are mainly collected through Statistics Canada, Statista, and relative academic studies. The data supports the hypotheses and predictions and explores the correlation between AI and higher education as well as employment dynamics in Canada.

Table 2. *Hypothesis and Source of Data Collection*

Hypothesis	Definition	Source
1	Null:The Canadian Government has no financial allocations for AI technologies over 10 years. Alternative:The Canadian Government has increasingly allocated funds for AI technologies over 10 years.	Departments of Finance Canada, 2024, Innovation, Science, and Economic Development, 2024, 2022, 2021, Government of Canada, 2019
2	Null: The application of AI does not increase job replacement in Canadian Universities. Alternative: The application of AI increases job replacement in Canadian Universities.	StatCan 2023
3	Null: There is not limited accessibility to higher education for low-income families in Canada due to the emergence of AI. Alternative: There is limited accessibility to higher education for low-income families in Canada due to the emergence of AI.	Statistics Canada 2025
4	Null: Increasing higher education costs does not negatively affect students attending universities in Canada. Alternative: Increasing higher education costs negatively affects students attending universities in Canada.	StatCan 2024a, StaCan 2024b

Data Analysis

In this study, eight features were selected (as presented in Table 3), based on their strong correlation with the research hypotheses as well as their alignment with domain knowledge. The random forest is chosen as the key predictive method for this classification problem due to its capability to handle mixed numerical and categorical variables, and reducing the chance of overfitting (Tang & Ishwaran 2017). Moreover, bootstrap takes random subsets of data points from the training set due to reducing overfitting, creating diversity, and working with high dimensional data to improve generalization (Borislava 2021). Finally, K-fold cross-validation maximizes the use of limited data by allowing each observation to serve as both training and validation data, thereby improving model reliability and reducing the risk of overfitting (Krstajic et al. 2014).

Feature Selection Rationale

The selection of eight features for this study (as presented in Table 3) is based on their strong correlation with the research hypotheses as well as their alignment with domain knowledge. The inclusion of domain-specific variables is critical for ensuring the validity and reliability of predictive models, particularly in complex, policy-driven areas such as AI funding and its societal impact. For instance, when examining whether the Canadian federal government has increased its allocation of funds to AI over the past decade, it is essential to include the federal government's AI funding data as a primary feature. This variable directly reflects policy decisions and budgetary trends related to AI investment. Excluding such a feature would weaken the model's explanatory power and reduce the conclusions' accuracy.

Table 3. *Predictive Model features (Secondary Data)*

Year/ Features	2017	2018	2019	2020	2021	2022	2023	2024	2025
Federal Funds allocation to AI (Million)	125	230	795	1000	401.6	443	2570	2403 .5	2388.61
Federal Funds allocation to Education (Million)	3170. 3	3331. 4	3587. 1	3788. 7	4166. 6	4037. 7	4258. 5	4800	4844.67
Undergraduate tuition fees for Canadian citizens	6618	6822	6468	6580	6660	6871	7152	7360	7252.07
Enrolled students Number in Higher Education	21200 00	21600 00	21800 00	21700 00	21900 00	22000 00	N/A	N/A	2245428 .57
Number of people with low income	30080 22	30681 68	31350 86	31692 46	31860 55	32474 02	33284 21	N/A	3407956 .07
Number of cases of data violation due to AI in Education	N/A	N/A	N/A	42	125	100	173	N/A	210
Number of Studies on Academic Misconduct due to AI	75	65	100	35	N/A	N/A	N/A	N/A	25
Whether Misuse of AI on Academic Dishonesty in Higher Education	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes
Whether AI Has a Negative Impact on Education	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes

Similarly, in predicting whether AI will have a negative impact on higher education in 2025, domain knowledge dictates that variables such as the number of reported data violations caused by AI in educational settings and the frequency of AI misuse in academic dishonesty should be prioritized. These features are instrumental in capturing trends related to the ethical and security concerns surrounding AI implementation in higher education. By incorporating these factors, the study ensures that the predictive analysis is both comprehensive and grounded in empirical evidence.

Exploratory Data Analysis (EDA)

During the exploratory data analysis phase, several key variables emerged as highly correlated with the predictive target variable, notably whether misuse of AI in academic dishonesty in higher education demonstrated a significant association with the predicted outcome (see Table 4). These features exhibited strong predictive relevance when analyzing AI's impact on higher education from 2017 to 2024.

Table 4. *Feature Importance in Random Forest Model*

Feature	Feature Importance
Funds allocation to AI by Federal Government	-0.590022
Fund allocation to Education by Federal Government	-0.686978
Undergraduate tuition fees for Canadian citizens (CAD)	-0.719605
Number of students enrolled in postsecondary institutions (Millions)	0.654468
Number of people with graduate education certificate (college/university)	0.993843
Number of people with low income (bottom quantile)	0.996091
Number of cases of data violation due to AI in Education	0.323092
Global Number of Studies on Academic Misconduct due to AI	0.340879
Whether Misuse of AI on Academic Dishonesty in Higher Education	1.000000

Note: This table shows the ratio of importance of different features.

For example, historical data from 2017 suggests that AI had a negative impact on higher education, primarily due to increasing incidents of AI misuse in academic settings. The presence of these three features in the dataset provided strong predictive signals, supporting the hypothesis that AI-related ethical concerns in education have intensified over time.

The analysis was conducted using Google Colab. After loading and preprocessing the dataset, including the handling of missing values, the target variable was defined. The analytical framework then incorporated Bootstrap resampling, Random Forest classification, K-fold cross-validation, and target value prediction. The complete implementation code is provided in Appendix A. This analytical approach addresses common dataset limitations, including missing values and limited data availability, while also providing predictive results through established performance metrics.

Data Limitations and Model Selection

Despite the robustness of the selected features, the dataset is constrained by certain limitations. The descriptive data consists of only nine features and eight descriptive values, which restricts the breadth of insights that can be derived.

In addition to categorical data handling, missing values was addressed to prevent biases and inconsistencies in the analysis. This study's most commonly employed techniques for handling missing data are mean imputation for numerical variables and mode imputation for categorical variables. Using the mean for numerical data ensures that missing values are replaced with the average of the available data, which is computationally efficient and preserves the overall distribution of the dataset. Similarly, mode imputation is used for categorical variables, replacing missing values with the most frequently occurring category. This method minimizes the introduction of bias while maintaining the structural integrity of the dataset.

Given these data characteristics, the Random Forest algorithm is identified as the most suitable classification model for this predictive analysis. Random Forest is particularly advantageous for this study because it efficiently handles numerical and categorical data. Additionally, it is well-equipped to manage missing data and mitigate overfitting, which is a common challenge in predictive modeling (Tang & Ishwaran 2017). The algorithm's ensemble learning approach enhances model stability and generalizability, making it an appropriate choice for analyzing the complex relationships between AI policies, ethical concerns, and their subsequent impact on higher education.

Predictive Model Development

As established in the previous section, Random Forest serves as the primary predictive model for this study due to its robustness in handling both numerical and categorical variables, its ability to manage missing data, and its effectiveness in reducing overfitting. One of the key techniques used in Random Forest is bootstrap aggregation (bagging), which improves model generalizability by creating multiple subsets of the training data. Bootstrap sampling involves randomly selecting data points with replacements, allowing some data points to be selected multiple times while others may be excluded from a given subset (Borislava 2021).

Table 5. *Three Bootstrap Indices of the Trees in Random Forest*

Tree 1	Bootstrap Indices:	[4 0 1 2 3]
Tree 2	Bootstrap Indices:	[4 4 0 0 0]
Tree 3	Bootstrap Indices:	[1 0 0 1 1]

For instance, Table 5 illustrates three bootstrap indices generated during training. In one specific bootstrap sample, the dataset includes features such as funds allocated to AI by the federal government, the number of individuals with graduate education certificates, and funding allocated to education by the federal government. The repetition of certain features within the bootstrap sample reflects the nature of resampling with replacement, which enhances model's stability by ensuring diverse training subsets.

Cross-Validation Strategy

Cross-validation is employed as a model validation technique to maximize the utility of the available dataset. Given the imbalanced nature of the dataset, stratified K-Fold cross-validation is utilized to ensure that each fold maintains a similar distribution of the target variable, thereby preventing biased performance estimates (Krstajic et al. 2014). The model is configured with n_splits = 5, meaning the dataset is divided into five folds, each serving as a validation set once while the remaining four folds are used for training. This configuration provides a balance between computational efficiency and reliable performance estimation.

Increasing n_splits to 10 could improve the performance by providing more training iterations; however, this adjustment would also increase computational time. Therefore, the choice of n_splits = 5 represents a trade-off between model accuracy and computational efficiency. Additionally, a random_state value of 42 is set to ensure reproducibility of results, which is a standard practice in machine learning research to maintain consistency across multiple experiment runs.

After executing the Random Forest model for predictive analysis, the model's performance is evaluated using multiple statistical measures, including Bootstrap Mean Accuracy, Cross-Validation Mean Accuracy, and a classification report that assesses Precision, Recall, and the F1 score. These evaluation metrics comprehensively assess the model's predictive capabilities and reliability.

Model Performance Metrics

a. Bootstrap Mean Accuracy

The Bootstrap Mean Accuracy is recorded as 1.0, indicating that the model achieves an average accuracy of 100% when trained repeatedly using bootstrap sampling (See Table 6). This metric reflects the model's ability to maintain consistent predictive accuracy across multiple resampled training subsets.

b. Cross-Validation Mean Accuracy

The Cross-Validation Mean Accuracy is also 1.0 (See Table 6), signifying that the model achieves perfect accuracy when evaluated through cross-validation. This result suggests that the model performs consistently well across different validation folds, further reinforcing its predictive reliability.

Table 6. *Evaluation of the Predictive Model*

Bootstrap Mean Accuracy:	1.0		
Cross-Validation Mean Accuracy:	1.0		
Classification Report:	precision	recall	f1-score
	1.00	1.00	1.00

Note: This table shows Bootstrap Mean Accuracy, Cross-Validation Mean Accuracy, and Classification Report.

Classification Report: Precision, Recall, and F1 Score

Precision = 1.0 (See Table 6): This score indicates that the model does not produce any false positives, meaning that every instance classified as "Yes" is indeed correct.

Recall = 1.0 (See Table 6): A recall score of 1.0 suggests that there are no false negatives, ensuring that all actual "Yes" instances in the dataset are correctly identified.

F1 Score = 1.0 (See Table 6): The F1 score, representing the harmonic mean of precision and recall, is also 1.0, confirming that both precision and recall are perfectly balanced.

These results indicate that the Random Forest model performs flawless classification within the given dataset. However, while such results may initially appear to indicate a highly effective model, they also raise concerns regarding the model's generalizability to unseen data.

Potential Overfitting and its Implications

Despite the model's seemingly perfect performance, it exhibits signs of overfitting, meaning that it may be memorizing patterns in the training data rather than learning generalizable relationships. Overfitting occurs when a model performs exceptionally well on the training and validation data but may fail to maintain the same level of accuracy when applied to new, unseen data.

This study's primary cause of overfitting is the limited dataset size, which restricts the model's exposure to diverse patterns and variations. When training data is insufficient, the model may become overly sensitive to specific details in the dataset rather than developing a robust decision boundary that can generalize effectively. To mitigate overfitting, future iterations of the model could consider the following approaches:

- Expanding the dataset by incorporating additional data points to improve model robustness.
- Feature selection optimization to reduce complexity and prevent reliance on noise within the data.
- Regularization techniques such as pruning the decision trees within the Random Forest model.
- Hyperparameter tuning, including adjusting the number of estimators and tree depth to balance bias and variance.

Results

For Hypotheses 1 through 4, the results of the ANOVA tests indicate p-values of approximately 0.009618 (Table 7), 0.006998 (Table 8), and 0.000 (Tables 9-10), all of which are below the 0.05 significance threshold. Accordingly, the null hypotheses are rejected in favor of the corresponding alternative hypotheses.

Figure 1 shows that while funding for AI technologies has been inconsistent, federal allocations for postsecondary education have demonstrated a continuous upward trend over the study period. As depicted in Figure 2, Canada has a high AI occupational exposure and strong complementarity between AI and education. This suggests that AI integration in the sector is more collaborative than disruptive. The results suggest that AI functions primarily as a complementary technology rather than a substitute for human labor within the higher education sector, with limited evidence of short-term job displacement, based on the selected indicators. Figure 3 shows the correlation between the number of University graduates and household income highlighting that access to higher education remains somewhat limited for low-income families in Canada. This is evident from the lower ratio of university graduates to households in the lowest income quintile compared to higher-income groups. Figures 4-5 demonstrate that escalating higher-education costs are associated with reduced university participation in Canada. This relationship is reflected in the increasing ratio between average undergraduate tuition fees and post-secondary enrolment levels. Finally, Table 11 and Appendix A present the prediction results, indicating that AI is expected to have a negative impact on higher education in Canada in 2025. This anticipated decline is primarily attributed to concerns regarding data privacy breaches and the misuse of AI tools for academic dishonesty.

Table 7. *The ANOVA Test Result for Hypothesis 1*

ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	78865372.30	78865372.30	12.45	0.009618576868			
Residual	7	44343588.95	6334798.42					
Total	8	123208961.30						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Funds Allocation to AI (CAD Million)	2.34	0.66	3.53	0.00961857691	0.77	3.90	0.77	3.9

Table 8. *The ANOVA Test Result for Hypothesis 2*

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	6425.33	2	3212.67	39.5	0.006997793192	9.55
Within Groups	244	3	81.33			
Total	6669.33	5				

Table 9. *The ANOVA Test Result for Hypothesis 3*

ANOVA						
Source of Variation	SS	df	MS	F	P value	F critical
Between Groups	28108346045220.00	1	28108346045220.00	4816.65	0	4.75
Within Groups	70027902643.00	12	5835658554.00			
Total	28178373947863.00	13	5			

Table 10. *The ANOVA Test Result for Hypothesis 4*

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	322562247.10	1	322562247.10	870.33	0	4.20
Within Groups	10377341.91	2829	370619.35			
Total	332939589.00					

Figure 1. *The Impact of Canadian Federal Expenditures on AI and Postsecondary Education from 2017 to 2024*

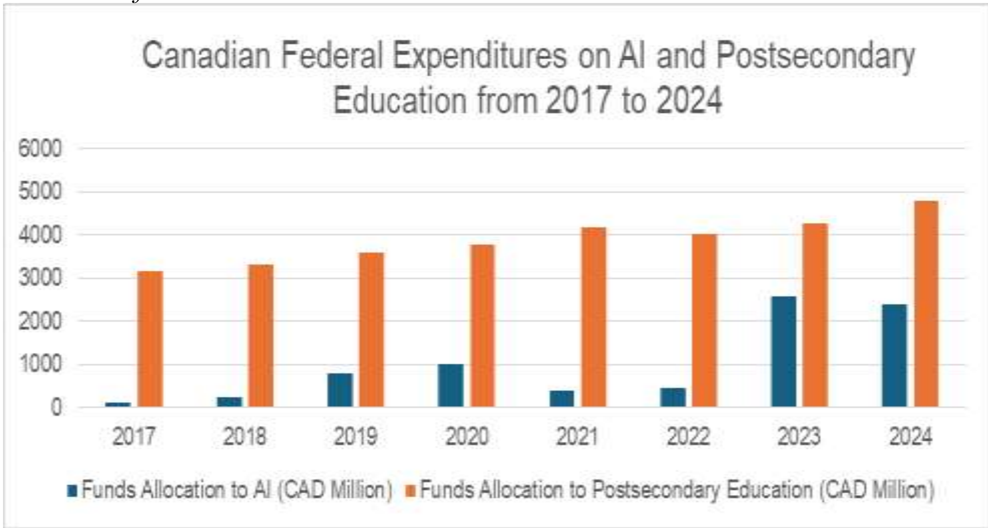

Figure 2. *Potential Artificial Intelligence Occupational Exposure and Complementarity across Occupations and Industries in Canada in 2021*

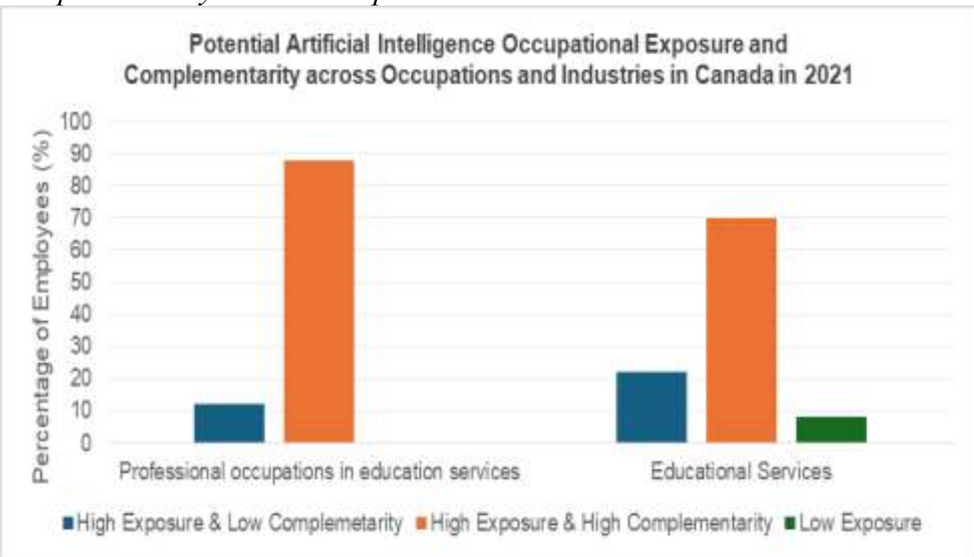

Figure 3. *The Number of University Graduates and Households in the Lowest Quintile in Canada from 2017 to 2023*

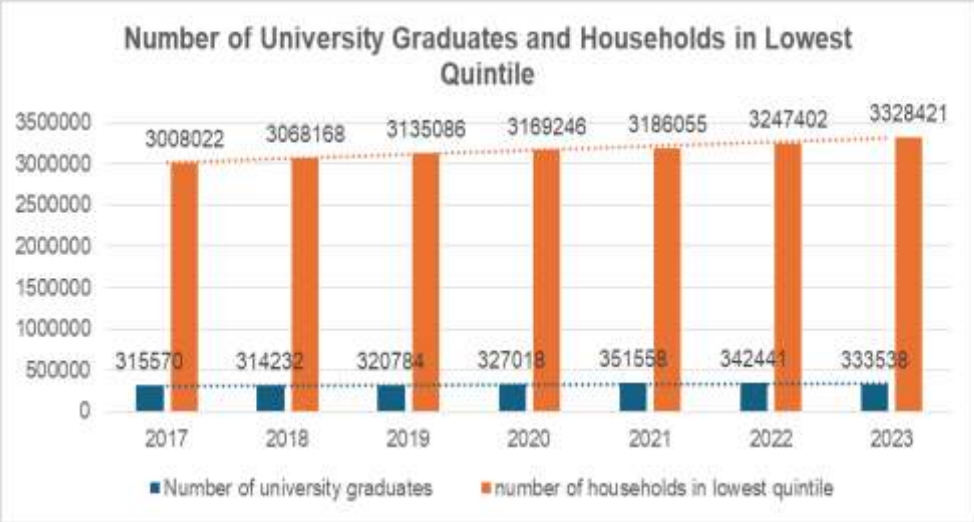

Figure 4. *The Average Undergraduate Tuition Fees for Canadian Citizens*

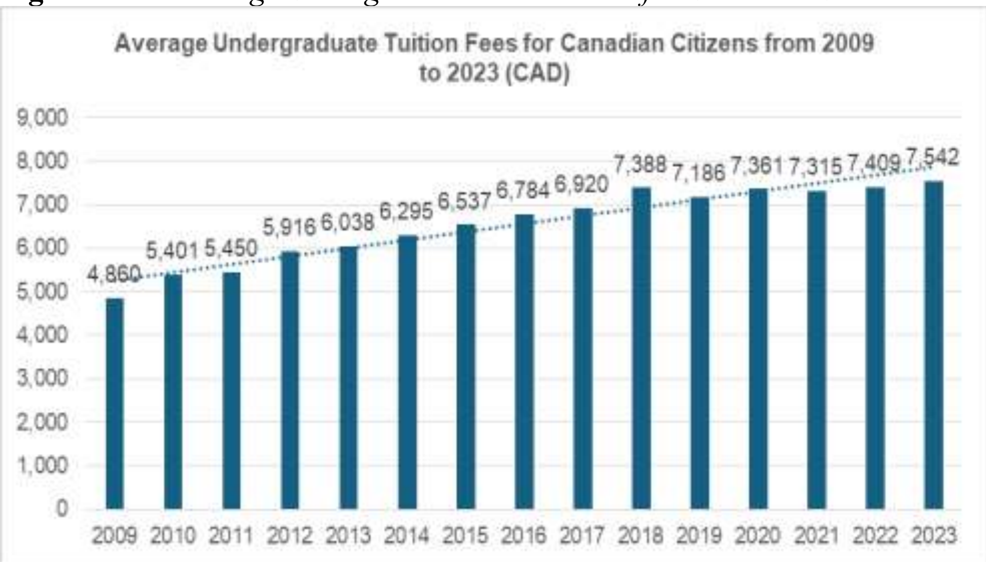

Figure 5. *The Number of Students Enrolled in Postsecondary Institutions in Canada from 2009 to 2023*

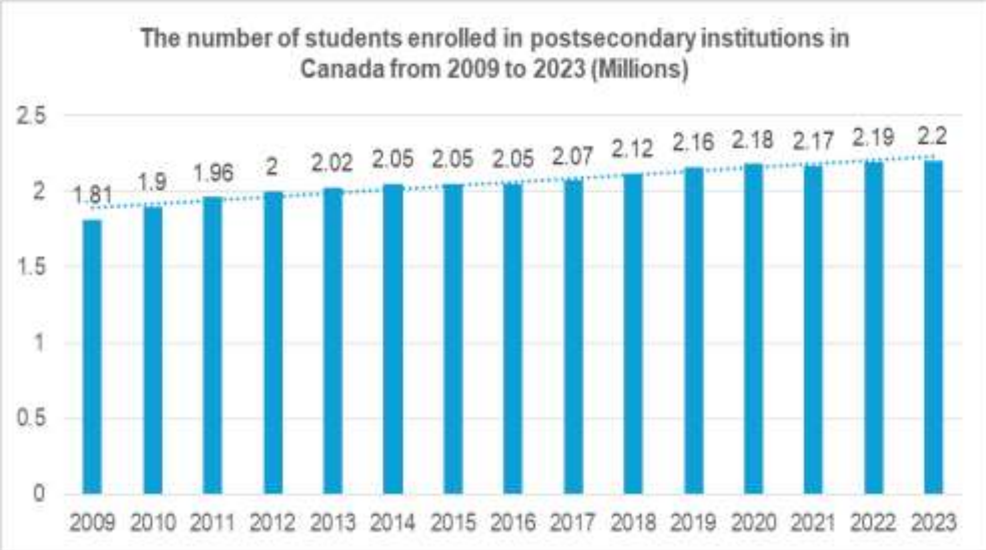

Table 11. *The Impact of AI Misuse on Academic Dishonesty in Higher Education*

Year	Whether AI is misused on Academic Dishonesty in Higher education or not
2017	Yes
2018	Yes
2019	Yes
2020	Yes
2021	Yes
2022	Yes
2023	Yes

Discussion

The findings of this study should be interpreted in light of several methodological limitations. Most notably, the analysis is based on a relatively small secondary dataset with limited temporal observations, which constrains the statistical power of both the ANOVA tests and the predictive model. In addition, the Random Forest model exhibited near-perfect accuracy, suggesting potential overfitting due to the limited sample size. As a result, the patterns identified in this study should be interpreted as exploratory rather than definitive.

In order to validate the hypothesis value, the ANOVA test was used if P-values are all less than 0.05, the results are proven to be significant.

The results of this study provide a nuanced understanding of the impact of AI on higher education accessibility, and employment dynamics in Canada. The findings suggest that AI may have introduced modest barriers to higher education accessibility for low-income families and may be associated with a slight deterrent effect on university enrolment, while simultaneously demonstrating greater complementarity than disruption within higher education employment in Canada.

Moreover, the study highlights a shifting trend in government funding priorities, particularly in the aftermath of the COVID-19 pandemic. During this period, the Canadian government has significantly increased its funds allocation toward AI development, often at the expense of direct funding for higher education institutions, which alleviates these significantly increasing requirements. This shift reflects broader national and global trends in technological investment, where AI is prioritized for its economic and strategic value. On the other hand, the gradual increase of funds from higher education infrastructure, research, and student support programs still requires Canada's post-secondary education system to consider long-term sustainability. Policymakers still need to carefully evaluate the trade-offs associated with AI investments to ensure that higher education institutions remain adequately funded and technologically equipped.

These findings are broadly consistent with recent literature on AI in higher education, while also adding a Canadian policy and employment perspective. For example, Osorio et al. (2024) and Sajja et al. (2024) emphasize that AI-supported learning systems can improve accessibility, personalization, and student engagement. However, the present study shows that these benefits may not be evenly distributed, as low-income families may still face barriers related to tuition costs, digital access, and broader socioeconomic inequality. This finding aligns with Danaher (2024), Chung and Freedman (2024), and Austin et al. (2023), who argue that AI systems can reproduce or deepen existing inequalities when biased data, unequal access, or uneven institutional deployment are not properly addressed.

The results also support the more cautious findings of Ivanov (2023), Habib et al. (2024), and Vistorte et al. (2024), who identify academic dishonesty, reduced creativity, emotional limitations, and ethical concerns as emerging risks of AI use in higher education. In this study, the predicted negative impact of AI on higher education in 2025 is similarly linked to academic misconduct and data-privacy concerns. At the same time, the employment-related findings are more consistent with Damioli et al. (2024) and Wong (2024), who suggest that AI does not simply eliminate jobs but reshapes labour demand and skill requirements. In the Canadian higher education context, the results indicate stronger AI complementarity than job substitution, suggesting that AI may support academic and administrative work rather than immediately replacing university employees. Therefore, this study extends the existing literature by showing that AI’s effects in higher education are mixed: it may enhance efficiency and innovation, but it can also intensify equity, integrity, and governance challenges if not supported by inclusive funding and responsible institutional policies.

Conclusion

As shown in the results and findings, AI slightly limits the accessibility to higher education for low-income families and the increasing higher education cost negatively impacts students attending universities in Canada. Additionally, AI has a negative impact on higher education in Canada due to serious data violation and misuse of AI on academic dishonesty in higher education. Meanwhile, the Canadian government shows the upward trend for funds allocation for higher education, but funding for AI technologies has been inconsistent, particularly after COVID-19. On the other hand, advanced AI technologies result in concerns about employment, particularly job loss and job replacement in Canada, but these concerns are likely to be avoided in the higher education industry, which is a high AI occupational exposure and high complementarity in Education.

Nomenclature

Definition of Main Variables

Number of cases of data violation	The number of data misuse of students and employees' information (Statista 2023).
Number of Studies on Academic Misconduct	The number of data misleading academic researchers and students to generate incorrect content as a result of losing the research abilities in higher education (Ivanov 2023).
Binary variables related to AI misuse	The AI misuse mainly due to the use of biased data to result in mismatch between students and institutions and reinforce the inequality in higher education (Austin et al. 2023).

References

Austin T, Rawal BS, Diehl A, Cosme J (2023) AI for Equity: Unpacking Potential Human Bias in Decision Making in Higher Education. *AI, Computer Science and Robotics Technology* 2023(2): 1–17.

Borislava V (2021) The Proportion for Splitting Data into Training and Test Set for the Bootstrap in Classification Problems. *Business Systems Research* 21(1): 228–242.

Bressane A, Zwirn D, Essiptchouk A, Saraiva ACV, Carvalho FLDC, Formiga JKS, et al. (2024) Understanding the role of study strategies and learning disabilities on student academic performance to enhance educational approaches: A proposal using artificial intelligence. *Computers and Education: Artificial Intelligence* 6(Jun): 100196.

Chung RY, Freedman B (2024) Health Inequalities in AI machine learning. In *Artificial Intelligence in Medicine*, 119–130. https://doi.org/10.1016/B978-0-323-95068-8.00009-1.

Damioli G, Van Roy V, Vertesy D, Vivarelli M (2024) Drivers of employment dynamics of AI innovators. *Technological Forecasting & Social Change* 201(Apr): 123249.

Danaher J (2024) Generative AI and the future of equality norms. *Cognition* 8(11): 251.

Departments of Finance Canada (2024) *Budget 2024: Supporting the Next Generation of Researchs and Innovators*. https://www.canada.ca/en/department-finance/news/2024/05/budget-2024-supporting-the-next-generation-of-researchers-and-innovators.html.

Elizabeth A (2024) Examine the Notion That AI Has Come to Replace Education Jobs in Classroom Teaching and Learning Done by Human Beings. *Bulgarian Comparative Education Society* 22. https://eric.ed.gov/?id=ED656178.

Government of Canada (2024) *Higher Education Research and Development Estimates, by funding sector and type of science. Data.* https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2710002501&pickMembers%5B0%5D=1.1&pickMembers%5

B1%5D=2.2&pickMembers%5B2%5D=3.1&cubeTimeFrame.startYear=2016+%2F+2017&cubeTimeFrame.endYear=2022+%2F+2023&referencePeriods=20160101%2C20220101.

Government of Canada (2021) *Higher Education Research and Development Estimates, by funding sector and type of science*. https://ised-isde.canada.ca/site/ai-strategy/=en.

Government of Canada (2019) *Budget 2019 Investment. Investing in the Middle Class*. https://budget.canada.ca/2019/docs/plan/budget-2019-en.pdf.

Habib S, Vogel T, Anli X, Thorne E (2024) How does generative artificial intelligence impact student creativity? *Journal of Creativity* 34(1): 100072.

Innovation, Science and Economic Development Canada (2021) *Views of Canadians on Artificial Intelligence: Final Report*. https://ised-isde.canada.ca/site/public-opinion-research/en/views-canadians-artificial-intelligence-final-report.

Innovation, Science and Economic Development Canada (2022) *Government of Canada launches second phase of the Pan-25 Canadian Artificial Intelligence Strategy*. https://www.canada.ca/en/innovation-science-economic-development/news/2022/06/government-of-canada-launches-second-phase-of-the-pan-canadian-artificial-intelligence-strategy.html.

Innovation, Science and Economic Development Canada (2022) *Pan-Canadian Artificial Intelligence Strategy*. https://ised-isde.canada.ca/site/ai-strategy/en.

Innovation, Science and Economic Development Canada (2024) *Artificial intelligence ecosystem*. https://ised-isde.canada.ca/site/ised/en/artificial-intelligence-ecosystem.

Ivanov S (2023) The dark side of artificial intelligence in higher education. *Service Industries Journal* 43(15/16): 1055–1082.

Jamie M, Barry M (2024) Preparing Educators and Students at Higher Education Institutions for an AI-Driven World. *Teaching & Learning Inquiry* 12(6): 1–9.

Jonathan S, Arsenii A, Marlyn CF (2023) The Gates Foundation's new AI initiative: attempting to leapfrog global health inequalities? *BMJ Global Health* 8(11).

Krstajic D, Buturovic L, Leahy D, Thomas S (2014) *Journal of Cheminformatics* 6(1): 1–15.

Osorio C, Fuster N, Chen W, Men Y, Juan AA (2024) Enhancing Accessibility to Analytics Courses in Higher Education through AI, Simulation, and e-Collaborative Tools. *Information (2078–2489)* 15(8): 430.

Raman R (2024).AI as a Catalyst for Change in International Student Admissions. In *2024 International Conference on Knowledge Engineering and Communication Systems*, 1–6.

Sajja R, Sermet Y, Cikmaz M, Cwiertny D, Demir I (2024) Artificial Intelligence-Enabled Intelligent Assistant for Personalized and Adaptive Learning in Higher Education. *Information* 15(10): 596.

StatCan (2023) *Number of students enrolled in postsecondary institutions in Canada from 2000 to 2022*. https://www-statista-com.eu1.proxy.openathens.net/statistics/447739/enrollment-of-postsecondary-students-in-canada/.

StatCan (2024a) *Average undergraduate tuition fees for Canadian citizens in Canada from 2008 to 2024*. https://www-statista-com.eu1.proxy.openathens.net/statistics/542989/canadian-undergraduate-tuition-fees/.

StatCan (2024b) *Number of university graduates in Canada from 2002 to 2022*. https://www-statista-com.eu1.proxy.openathens.net/statistics/449035/university-graduates-in-canada/.

Statista (2023a, April 15) *Artificial intelligence (AI) adoption worldwide 2022, by industry and function*. Statista. https://www.statista.com/statistics/1112982/ai-adoption-worldwide-industry-function/.

Statista (2023b) *Number of cases of data violation due to cyber attacks in the United States from 2020 to 2023, by industry*. Identity Theft Resource Center. https://www-statista-com.eu1.proxy.openathens.net/statistics/1318379/us-number-of-private-data-compromises-by-industry/.

Statistics Canada (2025) *Distributions of household economic accounts, number of households, by income quintile and by socio-demographic characteristic. Statistics Canada*. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610010101&pickMembers%5B0%5D=3.1&cubeTimeFrame.startYear=2017&cubeTimeFrame.endYear=2023&referencePeriods=20170101%2C20230101.

Tang F, Ishwaran H (2017) Random Forest Missing Data Algorithms. *Statistical Analysis & Data Mining* 10(6): 363–377.

Thanthong-Knight R (2024, April 5) *Canada Unexpectedly Sheds Jobs, Unemployment Rises to 6.1%*. Bloomber.com. https://www.bloomberg.com/news/articles/2024-04-05/canada-unexpectedly-shed-jobs-nemployment-rose-to-6-1.

Vistorte AOR, Acosta AD, Ayala JLM, Barrasa A, Granero CL, Gonzalez MM (2024) Integrating artificial intelligence to assess emotions in learning environments: a systematic literature review. *Frontiers in Psychology* 15(Jun).

Wong LPW (2024) Artificial Intelligence and Job Automation: Challenges for Secondary Students' Career Development and Life Planning. *Merits* 4(4): 370–399.

Appendix A

The Detailed Code of Data Analysis can be accessed via the following link: https://github.com/AbbyGholidoust/Supplementary-Materials-for-Athens-Journal-of-Science/tree/main.

Athens Journal of Sciences - Volume 13, Issue 3, September 2026 – Pages 221-252

Architectures, Energy Landscapes and Hydro-social Territories of Reclamation

By Mariacristina D'Oria[*] & Thomas Bisiani[±]

The employment of water resources as a driving force for productive activities has generated a wide taxonomy of methods and strategies for managing and harnessing energy from this natural element. From this perspective, land reclamation areas hold considerable importance, as their very configuration and morphology can be interpreted as a moving witness to human efforts to regulate and shape water, generating a complex system of intertwined and interdependent relations between hydraulic regulations, irrigation artifacts, and energy production networks. By exploring how the current ecological and energy crises are reshaping disciplinary lexicon, the research intercepts three key terms—ritratto, eco-machines, and hydro-social territories—, employing them to reinterpret aquatic landscapes. It examines three international case studies—2050: An Energetic Odyssey, Jade Eco Park, and Environmental Park—to identify design strategies that integrate ecological awareness with hydro-infrastructure at various scales. These inform a speculative project in the Lower Fiulian Plain, Italy, proposing adaptive reuse of hydraulic systems to accommodate rising waters and enable ecological re-colonization. The research explores a potential fourth phase beyond Lewis Mumford's framework: eotechnic, paleotechnic, and neotechnic. By delineating a possible eco-technic era, the work projects new possibilities for the architecture and landscape disciplines to rebalance the technosphere and biosphere for more resilient hydro-social landscapes.

Keywords: *environmental machines, hydro-social territories, renewable energies, bodies of water, ecotechnic era*

Intertwined Bodies: Humans, Water, Ground, and Energy

That between humans and water is an everlasting relation. Water, which constitutes approximately 60% of the human body, plays a crucial role in vital functions such as nutrient transportation, body temperature regulation, metabolic processes, and waste elimination. These very operations can be transposed on the territorial body, within which the aquatic body, through its transience or stagnant presence, influences and modulates the biodiversity of the ground, the humidity of the air, and the atmospheric conditions (Figures 1-2). A fundamental presence that, along the XVI century, was clearly remarked on and implicitly present in the very nomenclature of the Earth, referred to as "terraqueous globe"[7], with a mixed composition of water and land. Conceiving the Earth as a terraqueous globe implied the need for tools able to define, with precision, the boundaries and internal logic between ground and water, in order to trace limits and frame possibilities for expansion.

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[7]Definition given by the author within his book (Farinelli 2007, p. 120).

Figure 1. *Diagram of the Human Body in Relation with its Environment, from the Project Phase Shifts Park by Catherine Mosbach, Philippe Rahm, Ricky Liu & Associates Architects+Planners, Taichung, Taiwan, 2011-2014*

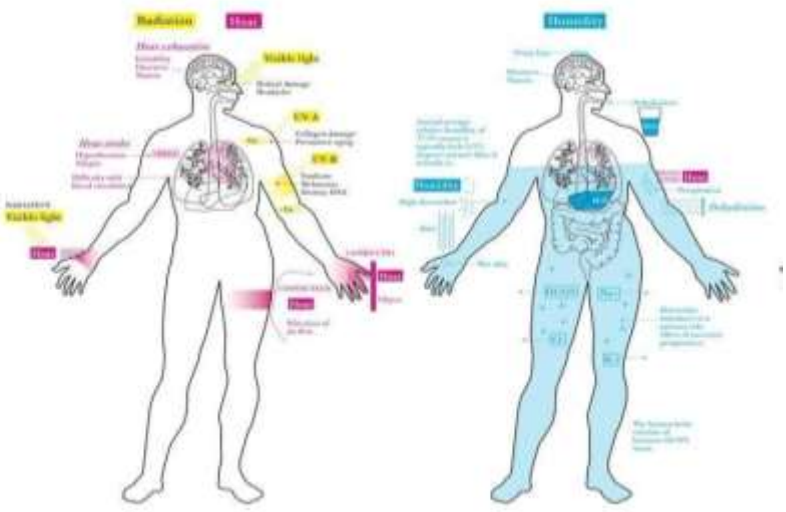
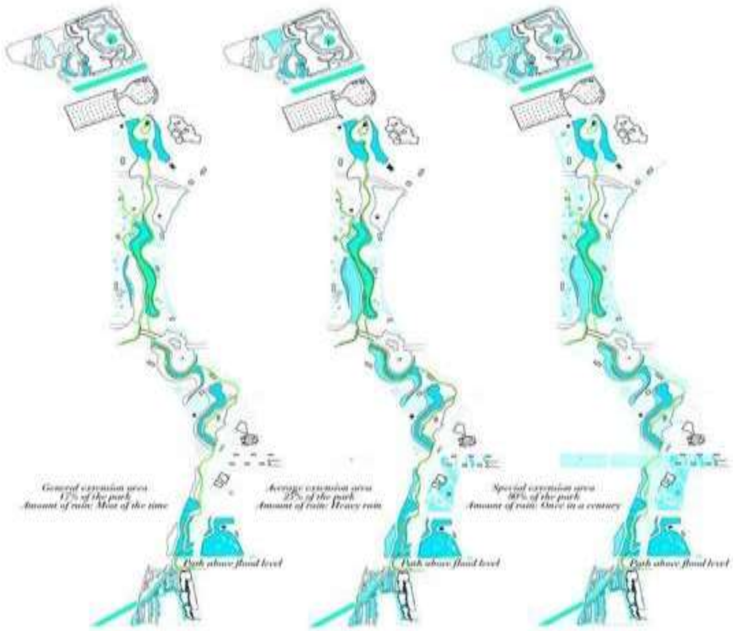


Figure 2. *Litosphere Design, from the Project Phase Shifts Park by Catherine Mosbach, Philippe Rahm, Ricky Liu & Associates Architects+Planners, Taichung, Taiwan, 2011-2014*



Therefore, water and humans are connected by a complex relationship in which water supplies the needs of humans for settlements and living, on the one hand, and is controlled and managed by humans to inhabit territories and produce energy on the other. Among the operations dealing with the hydric resource stands the reclamation activity, which embodies a consistent concretization of this long-term tension and has been systematically pursued from the Etruscans onward, conquering space for human settlements and agricultural fields. The operations displaced through the reclamation should also be read in strict connection with power agencies. Its system of practices and techniques is not a bottom-up operation but rather a sort of total planning driven by the idea of converting a landscape into an organism designed to function like a machine, reshaped by humans to expand within newly conquered wetlands and channel its flows to produce energy.

The exploitation of these hydric resources' driving force has facilitated the development of a rich taxonomy of dispositifs for producing energy, a sequence of technological artifacts with a long-lasting history. In the seventeenth century, in the Netherlands, wind-powered water mills enabled the transformation of ever larger expanses of sea into dry land, converting what was liquid and mobile into solid and stable ground (Farinelli 2009, p. 67). Mumford recognizes that the roots of such an invention record much deeper origins: "A creative syncretism of inventions, gathered from the technical debris of other civilizations, made possible the new mechanical body. The waterwheel, in the form of the Noria, had been used by the Egyptians to raise water, and perhaps by the Sumerians for other purposes; certainly, in the early part of the Christian era, watermills had become fairly common in Rome." (Mumford 1934, p. 108).

The contemporary looming environmental collapse, climate change, and energy crisis directly affect the hydric resource and all the practices and environments associated with it. Thus, the architectural discipline is asked to confront the urgent call for innovative strategies and logic to operate within the environment, seeking two main objectives: on the one hand, the preservation of the "natural" resources and their management; on the other, the search for new sources of renewable energies and new forms of sustainable living. In this context, the concept of energy landscapes began to emerge, explicitly highlighting the close connection between energetic crises and how the architectural discipline addresses them through designing spatial transformations across all scales. As stated in the editorial's notes of the Ardeth's issue, dedicated to *Energy Landscape* (Fall 2023), "the connection between environmental collapse and architectural discipline operates in two directions: from the climate and energy crisis to space construction and, conversely, from the design of the built environment to its effects on climate, energy resources, and the environment. Architectural design, therefore, presents both a challenge and an opportunity – one that we must find a way to address." (The Editorial Board of Ardeth 2023, p. 6).

The research, adopting this double-directional perspective, intends to explore an energy landscape deeply intertwined and shaped by water: the landscape of reclamation, with the aim of retracing new ways of approaching and rebalancing the weak environmental condition it is currently experiencing.

Thus, the work investigates the latent potentialities of the reclamation landscapes, starting from a first operation of lexicon revision, according to the new terms and values emerging within the contemporary debate, to open a reasoning on the possible new terms and values through three case-study analyses. The framework thus constructed then experiments with the Lower Fiulian Plain, an Italian area of agricultural reclamation, interpreting it as an operational field of application and a speculative experimentation space to confront the threats materialized by the current ecological, environmental, and energy crisis. The Lower Fiulian Plain offers a peculiar field of investigation that overpasses the technological sphere of mere water management, embracing a stratified system of values and nuances: cultural, geographical, social, and symbolic. In fact, not only has this landscape been a field of experimentation for increasingly advanced technologies, but it has also been, and still is, the domestic space for a group of communities that have stratified within its terraqueous surface, encompassing social practices, personal histories, working efforts, agricultural cultures, public spaces, and collective memories.

The reinterpretation of landscape machines and the shift toward a hydro-social perspective require the formulation of a renewed design lexicon, capable of articulating new relations between the previously discrete technosphere and biosphere, and of expanding the operative scope through which the territory can be read as a complex multiscalar network. If, as underlined by Lewis Mumford, water as a source of energy production encompasses three technological phases – *eotechnic*, *paleotechnic*, and *neotechnic* – the core research question of this work emerges: What shape will land reclamation territories assume in a *post-neotechnic* era? What new forms of coexistence between humans and machines can be envisioned to respond decisively to the current ecological, environmental, and energy crises?

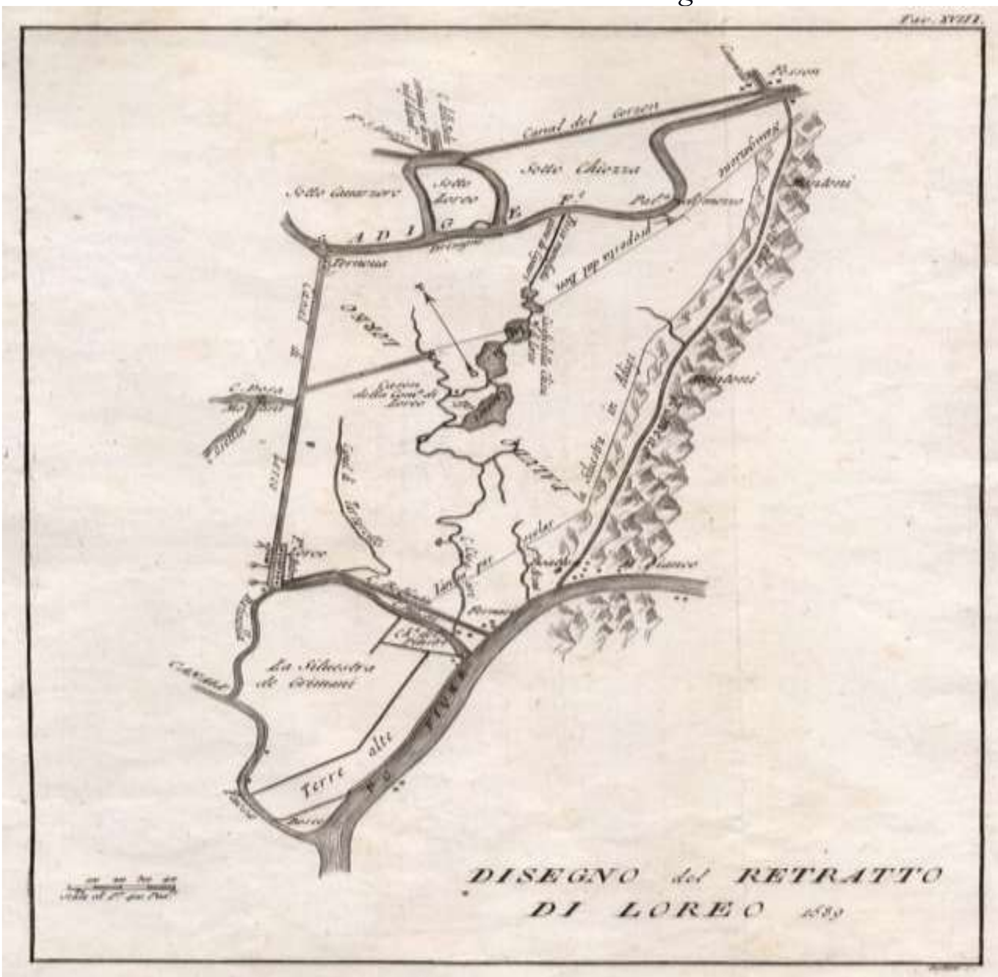
The original contribution of this work lies in the proposal of a design taxonomy and a conceptual framework for the ecotechnic era. Moving beyond a preliminary lexicon revision, the research provides an operational tool for designers by defining the 'environmental machine' as a metabolic system where energy production, ecological coexistence, and inhabitation practices are interactively integrated. By distilling strategies from comparative case studies, this paper establishes a three-fold taxonomy of intervention: water as a strategic environmental-energetic-social infrastructure; the definition of multi-sensory climatic clusters; and micro and diffused systems of amphibious artifacts. This integrated framework serves as a projective methodology to reconfigure reclamation landscapes into resilient hydro-social territories, effectively rebalancing the relations between the technosphere and the biosphere within the architectural discipline.

Amphibious Geographies: Hydro-Social Territories Seeking for Reinterpretation

The reclamation landscape can be introduced by the reasoning of Farinelli. "Who studies the historical cartography of the Po Valley often encounters the term *'ritratto'* (or *retratto*), which in ancient documents refers to a strip of land from which water has receded, either through the gradual addition of soil (reclamation) or through artificial drainage, i.e., simple drying (§ 31), a process that has affected parts of Europe since the early Middle Ages [Ciriacono 1999] and which, in the 19th century, at the time of mechanical water pumps, took on the name 'bonifica' in Italy. It should be noted that even today, a *ritratto* (portrait) is exactly the same thing, a flat surface on which all moisture (that of the painter's colors) has been removed. It should be noted, in passing, that for us, a portrait is still exactly the same thing, a flat surface on which all moisture (that of the painter's colors or the photographic emulsion) has dried. In other words, the only difference is that while the portraits we are used to are images of living beings, the "portrait" found on the maps of the past is an image of the table itself, of the flat, continuous, homogeneous, and isotropic extension that serves as the archetype of the modern state: precisely the expanse that, in its purest but at the same time most material form, the reclamation, promoted at the beginning by the state itself, generates and exemplarily brings to light as its ideal model." (Farinelli 2009, p. 87).

Figure 3. *Map Representing the Cut of Porto Viro, Po Delta, 1600–1604*

Figure 4. *Bernardino Zendrini, Disegno del Retratto di Loreo, 1589, in the Work "Memorie storiche dello stato antico e moderno delle lagune di Venezia"*



Literally, a strip of land from which water has been forced to recede, a multitude of technologically driven operations has shaped reclamation landscapes focused on drying the water from previous, unhygienic wetlands, domesticating them, and putting them to work within agricultural processes (Figures 3-4). Thus, these areas are no longer natural environments but somewhat artificially shaped territories, constellated by an archipelago of hydraulic infrastructure that stores, distributes, and drives water throughout them. The image one should envision is that of an active management and care operation, which continuously rebalances the water flows according to the production requested and, more recently, also to the necessity of protection from extraordinary meteorological phenomena. This peculiar functioning leads to the interpretation of these landscapes where water has been removed as heterogeneous organisms that integrate nature, human activities, agricultural production, and energy production, organisms highly infrastructured –channels, hydraulic regulations, irrigation artifacts, drainage systems, mechanical water pumps– conceived as "landscape machines". The combination of the words "landscape" and "machine" has been long discussed and interpreted with a negative connotation related to the impoverishing effects of "limitless domination of a globalizing technology, a threat," (Meyer 2008) a negative reading of the landscape that necessitates a shift in perspective. In fact, among these negative connotations, few authors reasoned on this relation in positive terms: "For Olmsted, parks performed in two ways: they were environmental cleaning machines, open spaces of healthy sunlight, well-drained soils, and shady green groves of trees reducing temperatures, absorbing carbon dioxide and releasing oxygen." (Roncken et al. 2011, p. 71).

In this sense, it can be helpful to underline the significance with which this term should be appropriated and interpreted nowadays, conceiving it as an inspiring concept to construct and shape resilient environments from a new balanced combination between the elements of the machine (*technosphere*) and of the natural ecosystem (*biosphere*), experimenting with systems capable of providing self-sustaining cycles including plants, water treatment, and heat transmission. In this sense, landscape machine "is directly congruent with agricultural developments over the past millennia [...] these are productive landscapes that not only can produce food and accumulate energy but also produce clean dredge, healthy soil, and freshwater at the same time, resulting in unfamiliar types of ecological biotopes that will create the sprouts of new origins of life"[8] (Figure 5).

Figure 5. *C. Vaux and F. L. Olmstead, Map of the Central Park, New York City, January 1st 1870*

The land reclamation areas are, thus, potential landscape machines on which to intervene, finding a new equilibrium of coexistence and interaction between environmental bodies, technology, and human activities. For instance, as shown in their work, Todd and Todd (1994) interpret the project as a tool for shaping "eco-machines", systems designed to treat wastewater or regenerate degraded environments through the combined use of plants, microbes, aquatic animals, and artificial structures. These "living machines" mimic natural ecosystemic processes, providing ecosystem services such as water treatment or biomass production.

The work of James Corner gives another relevant interpretation of this concept (Corner 1999). With his studio Field Operations, from 1998, he endures the configuration of "Living urban systems", defining ecological infrastructures capable of triggering evolutionary and transformative processes over time and promoting integration between ecology and urban planning.

[8]The term is coined to define: "co-constitution of water and society, rejecting the idea that water flows independently of the social contexts through which it moves". For further information (see Linton and Budds 2014).

Finally, before delving into the recent design experimentations, it is necessary to address one last crucial issue connected with these landscapes, which is directly related to their stratified memory of historical social practices. Reasoning on the longstanding challenge of managing water is not solely a technological issue tied to land use and agricultural production but is also fundamentally connected to how a territory is inhabited and traversed by social practices. The various ways water has been managed, infrastructured, and employed reveal different approaches to imagining and experiencing the territory, giving body to a heterogeneous sequence of social practices and inhabiting strategies. This historical and socio-spatial layering of water practices sets the basis for understanding contemporary approaches to water governance, which increasingly acknowledge the entanglement of ecological, political, and cultural dimensions in shaping hydric territories.

The complexity and urgency of intervening within this field are demonstrated, particularly from the mid-2010s onward, by a growing interest in water management and governance, which has led to the formulation of various concepts, each focusing on diverse dimensions and confronting different nuances of the vast hydric issue. These include, for instance, the *hydrosocial cycle*, *waterscape*, and *hydrosocial territories* (Boelens et al. 2016). In particular, hydrosocial territories foster critical reflection on the complexity involved in operating with and on hydric resources. The term has been defined as: "the contested imaginary and socio-environmental materialization of a spatially bound multi-scalar network in which humans, water flows, ecological relations, hydraulic infrastructure, financial means, legal-administrative arrangements, and cultural institutions and practices are interactively defined, aligned and mobilized through epistemological belief systems, political hierarchies, and naturalizing discourses. Hydrosocial territories (imagined, planned or materialized) have contested functions, values and meanings, as they define processes of inclusion and exclusion, development and marginalization, and the distribution of benefits and burdens that affect different groups of people in distinct ways" (Boelens et al. 2016, p. 2) (Figure 6).

Figure 6. *H. Corson-Dosch, C. Nell, R. Volentine, A.A. Archer, E. Bechtel, J.L. Bruce, N. Felts, T.A. Gross, D. Lopez-Trujillo, C.E. Riggs, E.K. Read. The Water Cycle Diagram, Water Science School, USGS, 2022*

Therefore, if the core research question of this work concerns the formulation of a fourth, contemporary phase of technological development, following the eotechnic, paleotechnic, and neotechnic phases delineated by Lewis Mumford, this phase may be identified as the *ecotechnic* era. This concept remains scarcely adopted within the disciplinary debate. However, an initial conceptualization can be traced in John Michael Greer's 2009 book *The Ecotechnic Future: Envisioning a Post-Peak World* (Greer 2009). Here, the author acknowledges this era as a moment when humans would reach a sustainable climax phase, blending ecological sustainability with advanced technological systems driven by renewable resources. A significant shift in perspective emerges from Greer's text. While Mumford elaborates the succession of technological eras from an anthropogenic perspective—focusing on the relations technology establishes with humans, in terms of social practices and productive systems—Greer introduces a substantial turn. The relationship with technology is no longer analyzed primarily from a human-centered perspective, but rather from what he calls "nature's eyes" (Greer 2009, p. 240), of which humans form only a part. He writes: "To see humanity's trajectory into the future in this way, ultimately, is to consider ourselves through nature's eyes [...], subject to the same natural laws and ecological patterns as every other living thing on Earth. Troubling though this view may be to the hubris cultivated by some recent human cultures, it reaches back to the older and more ecologically relevant ways of understanding humanity and nature common to traditional cultures [...] reach forward to ways of making sense of the world that will blossom in the far future, as the ecotechnic age dawns" (Greer 2009, p. 244).

The *ecotechnic* era envisions the integration of fundamental human and non-human concerns—food, dwelling, work, energy, community, culture, and science—through a decisive shift away from a purely anthropocentric perspective. It calls for a rebalanced relationship between the technosphere and the biosphere, between the technological components of machines and the ecological dynamics of ecosystems, encouraging the experimentation of systems capable of generating self-sustaining cycles and fostering new forms of multispecies coexistence.

Thus, reclamation landscapes appear to simultaneously embody the meanings and values of hydro-social territories—interfaces among society, technology, and nature—and the potential to act as contemporary landscape machines capable of rebalancing the threatened relationship between nature, humans, production, and sustainable energies.

The reinterpretation of landscape machines and the opening of a new perspective toward the hydro-social territories involve the formulation of a new design field of action capable of intertwining a renewed relation between the previously discrete technosphere and biosphere, adopting multidisciplinary strategies to read the territory as a complex multiscalar network.

Retracing a Taxonomy of Strategies to Configure Renewed Hydro-Social Territories

The research adopts a hybrid methodological approach that integrates theoretical analysis with the research-by-design method, utilizing the critical examination of case studies to inform projective spatial strategies for the reconfiguration of reclamation landscapes into hydro-social territories.

Developing a critical comparative reading of three emblematic design experiments, the contribution seeks to uncover original insights into how water can serve as an active medium to reconfigure relationships among environment, technology, and society.

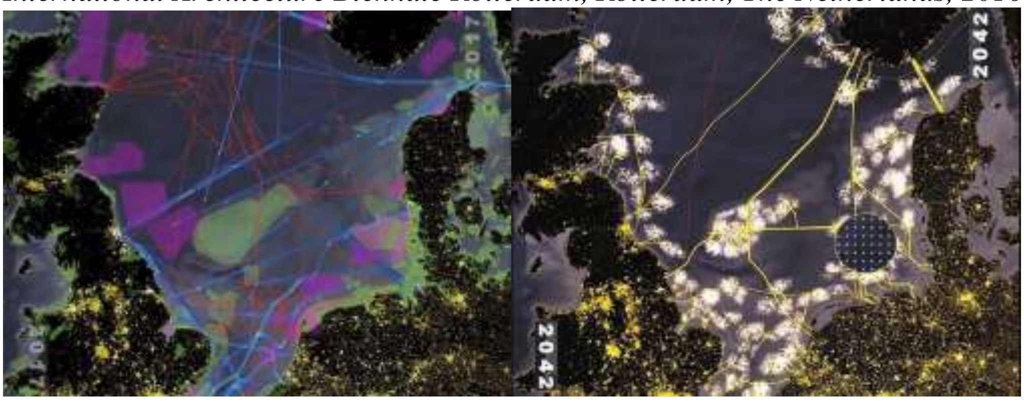
The selection of case studies carries methodological significance: the three projects were chosen to ensure a heterogeneity of scales—ranging from transnational-transterritorial to urban and local—and to illustrate distinct technological approaches to the hydric resource. Specifically, three core criteria guided the selection: relevance to the energy transition, highlighting projects that envision water as a driver for post-fossil energy landscapes; variety of scale, to test the scalability of hydro-social strategies through different spatial and temporal dimensions; and integration between the biosphere and the technosphere, selecting experiments that move beyond purely engineering-based control toward metabolic and ecological synergy.

What they share is the ambition to integrate energy production, ecological coexistence, and inhabitation practices within the same design process. Their comparison is therefore used to critically test the concept of the hydro-social territory and to trace an operative design genealogy capable of informing emerging *post-neotechnic* territorial scenarios.

In the context of current transformations in energy landscapes and the emergence of new territorialities linked to ecological transition, *2050 - An Energetic Odyssey* (2015-2016) by H+N+S Landscape Architects, developed with Ecofys and Tungsten Pro, stands as a paradigmatic example of a "narrative infrastructure" capable of articulating projective imagination and political vision. Presented in 2016 within the framework of the International Architecture Biennale Rotterdam (IABR), the project outlines a transnational vision of the North Sea as a collective renewable energy infrastructure. A twelve-minute animated simulation constructs an immersive vision—across space and time—depicting the progressive reconfiguration of the North Sea (Figure 7) into a post-fossil landscape of large-scale energy reclamation (Figures 8-9). It outlines a system of approximately 25,000 offshore wind turbines (10 MW each), connected through high-voltage networks, artificial conversion islands, and logistical maritime corridors.

Figure 7. *Satellite Photo of the Project Area Taken from Google Maps, 2025*

Figures 8-9. *H+N+S Landscape Architects, Still Images from the Animation "North Sea", IABR 2016 – THE NEXT ECONOMY, 7th Edition of the International Architecture Biennale Rotterdam, Rotterdam, The Netherlands, 2016*



This representation does not merely illustrate a technical transformation; rather, it constructs a territorial and cultural horizon in which energy production is embedded within a new design ecology. The North Sea is no longer portrayed as a neutral surface, but as a contested space — dense with practices, rights, and infrastructures — reconfigured through strategies of coexistence among energy production, marine ecology, and maritime mobility. In this sense, the project fits within a broader discourse on hydro-social territories, revealing how marine spaces are shaped by socio-technical, political, and ecological mediations, and how they function as productive devices for collective subjectivities.

Water is conceived as a territorial and infrastructural matrix, while landscape design operates not as aesthetic mediation but as an instrumental form of environmental governance that renders competing demands legible and negotiable. Moreover, the project extends the historical logic of Dutch reclamation: whereas in previous centuries land was reclaimed from the sea for agriculture, *2050 - An Energetic Odyssey* envisions a new kind of reclamation, in which the sea becomes a productive surface for sustaining a post-fossil society. This shift entails both a technical and a symbolic redefinition of space, and it repositions landscape architecture as an agent for territorial transformation and collective future-making.

While H+N+S' *Odyssey* operates at a transnational scale, interpreting water as a large-scale energy infrastructure, *Jade Eco Park* (2012-2016) in Taichung experiments with this resource as a catalyst for hydro-climatic transformation. Taiwan's tropical climate, influenced by the Kuroshio—one of the world's most significant sea currents— is warm and humid, with increasingly pronounced extremes. These geo-climatic conditions guided the design of Philippe Rahm Architectes, Mosbach Paysagistes, and Ricky Liu & Associates, who converted a former 67-hectare airport platform into a vast public park (Figure 10).

Figure 10. *Satellite Photo of the Project Area Taken from Google Maps, 2025*

The primary objective was to enhance climatic comfort, enabling residents to inhabit outdoor urban spaces more fully. The project employs water as a vector for ecological performance and public engagement, transforming the former transportation infrastructure into an ecological, convivial, and immersive one. It combines two main elements: the lithosphere—water, topography, and soil—and the atmosphere—heat, humidity, and pollution—to configure a sensory green lung structured into twelve atmospheric zones that, offering distinct climatic conditions, overlap, separate, densify, or dissipate across the park's surface, producing a range of atmospheres that visitors may select and appropriate—hence the name *Phase Shifts Park* (Figure 11).

Figure 11. *Aerial View of the Project Phase Shifts Park by Catherine Mosbach, Philippe Rahm, Ricky Liu & Associates Architects+Planners, Taichung, Taiwan, 2011-2014*

Figure 12. *The Meteors Dispositifs, from the Project Phase Shifts Park by Catherine Mosbach, Philippe Rahm, Ricky Liu & Associates Architects+Planners, Taichung, Taiwan, 2011-2014*

Thus, the design is modulated to shape a sequence of climatic variations throughout the site, in which heat, humidity, and atmospheric pollution are confronted with through three categories of dispositifs: cooling devices–such as the “Anticyclone”, “Underground Breeze” or “Blue Sky Drizzle”–; drying devices –including dense trees canopies, “Dry Cloud” or “Desert Wind”, and depollution devices –such as the “Ozone Eclipse” or the “Ultrasound Repellant Device” (Figure 12).

If in the previous case water served to develop a new energy infrastructure, in this project, it becomes the re-shaper agent of the public urban experience, able to configure climatic topographies and enable ecological and collective responses. Atmospheric flows, microclimates, and meteorological phenomena are conceived as integrated infrastructures shaped through technologies, governance, and narrative design.

The last case study presents a third, further, shift in relating to and managing water as a design element capable of reshaping the spatial and symbolic relationships between energy, architecture, and, in this specific case, the post-industrial city.

Located in the heart of Dora Park in Turin, *Environment Park* (1997-2000) represents a notable Italian case of urban regeneration, hydrotechnology, and environmental education (Figures 13-14). Since 1996, the park has hosted a technological campus that, as of July 2024, incorporates a micro-hydroelectric power plant exploiting a 5.5-meter head on the Meana Canal — a historical derivation of the Dora Riparia river. With an installed capacity of 434 kW, the plant produces approximately 3.8 million kWh annually, covering up to 80% of the park's energy demand and supplying electrolysis systems for hydrogen-powered urban vehicles.

Figure 13. *Satellite Photo of the Project Area Taken from Google Maps, 2025*

Figure 14. *Views of the Environmental Park, Inserted within the Park Dora, Turin, Italy*

The hydro plant's architectural envelope — featuring wooden louvers and a glazed technical room — allows visitors to observe the Kaplan turbine in operation, thereby merging architectural legibility with didactic function. Beyond electricity generation, the Meana Canal is also employed for passive cooling of office buildings in spring and autumn. The facility integrates within a broader eco-technological system that includes photovoltaic panels, biomass plants, green roofs, and closed-loop heat pumps.

This intervention on a former industrial brownfield — once occupied by the Fiat Ferriere steelworks — embodies an expanded notion of reclamation: not merely the recovery of a historical waterway, but its transformation into an energy and knowledge infrastructure for a future-oriented, carbon-neutral urban model. While H+N+S and Rahm operate at regional and climatic scales, Environment Park shows how similar strategies can be scaled down to the urban and metropolitan context. It exemplifies a hydro-social territory in the city: water becomes an active resource for energy production, climate mitigation, public awareness, and technological innovation, all housed within an architecture that is both functional and legible.

Completing this triptych of design approaches, Environment Park reveals how energy, landscape, and memory may be recombined through integrated reclamation strategies. It opens a fertile field for typological and systemic reflection on ecological transition landscapes.

The three case studies offer complementary yet differentiated approaches to the role of water in reshaping territorial infrastructures through landscape, technology, and architecture. Despite operating at distinct scales and within varied contexts, they can be read together as a comparative matrix outlining a broader typology of hydro-social territories.

Across all three projects, water is conceptualized as an active agent—not merely something to be contained or managed, but to be valorized ecologically, socially, and symbolically. In each case, through a deep interweaving of engineering and landscape, it becomes simultaneously infrastructure, medium, and design material: offshore wind and marine production in *2050 - An Energetic Odyssey* by H+N+S Landscape Architects; evaporative cooling and climatic modulation in *Jade Eco Park* by Philippe Rahm and Catherine Mosbach; and hydroelectric production in the redevelopment of *Environment Park* in Turin. All three embody a renewed balance between the techno- and biospheres: the technical component is not concealed but rendered visible, accessible, and pedagogical.

Beyond these shared premises, however, significant differences emerge. First, the projects diverge in scale and territorial ambition. *2050 – An Energetic Odyssey* operates at a transnational marine scale, articulating a long-term strategic vision for decarbonization across the North Sea basin. *Jade Eco Park* addresses the urban scale, through a systemic approach to climatizing and reprogramming public space within a dense metropolitan environment. *Environment Park*, by contrast, intervenes in a compact post-industrial context, regenerating a brownfield site through high-efficiency energy systems embedded in the existing urban fabric. Second, they deploy distinct design languages. *Energetic Odyssey* adopts a speculative and projective masterplanning mode, constructing a narrative vision that is simultaneously infrastructural and political. *Jade Eco Park* foregrounds sensory and atmospheric experience, making climate perceptible through bodily immersion. *Environment Park*, finally, embraces a technical-functional aesthetic oriented toward replicability and performance.

The modes through which water is rendered visible—or legible—also differ. In *Energetic Odyssey*, water is engaged through distributed offshore infrastructures. In *Jade Eco Park*, it acts as a microclimatic agent shaping localized thermal gradients and ecological niches. In *Environment Park*, it becomes a tangible and readable hydraulic device, embedded within urban memory and materially accessible to citizens.

Functionally and symbolically, the projects further diverge. While *Energetic Odyssey* operates primarily as a governance and visioning tool, projecting a collective energy future, *Jade Eco Park* models a resilient tropical urbanity in which climate adaptation and public space coincide, and *Environment Park* translates sustainability into a form of urban technological literacy, demonstrating how energy production can structure processes of regeneration and education.

Taken together, these cases articulate a threefold paradigm for contemporary hydro-social design: strategic systemic planning (H+N+S), climatic-sensorial architecture (Rahm and Mosbach), and urban technical regeneration (Environment Park). Their comparison reframes reclamation not as mere remediation, but as an integrated design praxis in which water becomes at once infrastructure, landscape, and cultural narrative. In doing so, they offer a methodological and operational framework for exploring the hydro-social territory as a space where landscape architecture mediates between natural resources, climate-responsive technologies, and collective subjectivities—shaping resilient, infrastructural, and experiential landscapes. In particular, these projects reveal certain strategies which, varying in scale and approach with regard to the use and interpretation of water in architectural and landscape design, can prove useful tools in the construction and enhancement of hydro-social territories, respectively: 1. water as environmental-energetic-social infrastructure; 2. climatic and sensorial dimension; 3. micro and diffused systems of amphibious artifacts.

Exploring the Transformative Potentials of Designing from the Lens of the Hydro-Social Territories: The Application to the Specific Case Study of the Lower Fiulian Plain

This analytical journey across, firstly, the theoretical frame and roots of hydro-social landscapes, and then, through the analysis of heterogeneous cases studies highlights the relevance of reconsidering reclamation landscapes through an alternative interpretative perspective. These territories still embody latent multi-scalar networks in which humans, water flows, ecological relations, hydraulic infrastructure, financial means, legal-administrative arrangements, and cultural institutions and practices are interactively intertwined.

In the current epoch, marked by climate change and its increasing tangible manifestations, it becomes necessary to delineate updated strategies and tools, to re-set, on the one hand, the nowadays-unbalanced equilibrium between resources and their exploitation –identifying new sustainable forms of living– and, on the other, of reframing a new vision of these territories capable of expanding the disciplinary operative ground, overpassing the technosphere, and retracing new sets of action. Reclamation landscapes, given both their anthropic origins and their strict and vital relationship with water bodies, represent a relevant field for testing new tactics and paradigms for post-neotechnic ecologies.

Engaging with water in territories where it is structurally pervasive has historically generated a stratified taxonomy of machines, technologies, and spatial practices, ranging from punctual architectural devices to territorial and transnational infrastructures. A contemporary evolution of this complex taxonomy, mirroring the urgent need to interpret the amphibious grounds, can be identified through the examined case studies, that allowed for the identification of three possible categories of intervention –defined according to scale (spatial and temporal) and field of action–: water as environmental-energetic-social infrastructure; the definition of new climatic and sensorial "clusters", and, finally, the micro and diffused systems of amphibious artifacts that permit the functioning of the whole system.

These categories may operate independently at a one-scalar intervention, yet they can also be interpreted as components of an integrated and processual framework unfolding across space and time.

Analytical Findings: Geo-Hydrological Characterization of the Lower Fiulian Plain

Building upon this analytical structure, this section tests the applicability of these strategies within a specific territorial context: the Lower Fiulian Plain (Figure 15), an agricultural reclamation landscape situated in the Friuli Venezia Giulia region of Italy. This area is bordered on three sides by bodies of water –the Tagliamento (west) and the Isonzo (east) rivers, and the Marano and Grado lagoons (south)– and its surface is crossed by five additional rivers and a vast and capillary hierarchical system of canals, embodying the anthropogenic shaping of water-bound origins.

Figure 15. *Satellite Photo of the Lower Fiulian Plain taken from Google Maps, 2025*

The proposed scenario reinterprets this landscape not merely as a productive agricultural machine, but as a strategic socio-ecological infrastructure –functioning simultaneously as a catalyst for biodiversity, a renewable energy field, and an alternative to urban life.

Water as Environmental-Energetic-Social Infrastructure

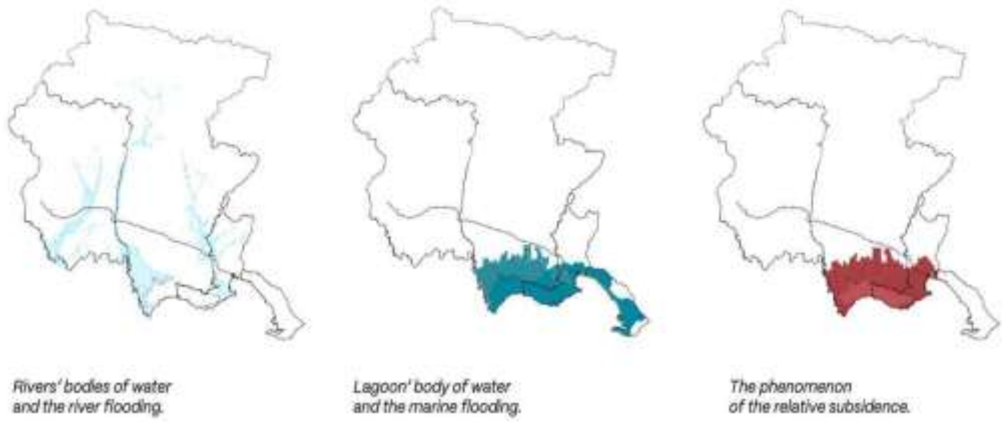
As previously observed, reclamation landscapes exhibit particular characteristics that differ from all other rural landscapes: they have been materially produced and shaped by anthropogenic hydraulic manipulation. Land emerged through processes of extraction, drainage, and regulation through various techniques and operations. In this sense, water here does not represent only a vital resource, but the very condition of existence of these landscapes.

If we recall the first image introduced at the beginning of this contribution –the anatomy of the human body and its constitutive relation to water– reclamation territories may be understood analogously: water acts simultaneously as natural regulating infrastructure and as the generative and repairing matrix from which recovering operations can begin; constituting both the element historically controlled and the medium through which new ecological equilibria may be reached.

In the contemporary context, where hydric protection, water preservation, and ecological reinforcement demand urgent disciplinary responses, such landscapes provide a relevant ground for experimentation and testing.

The Lower Fiulian Plain, whose water-anatomic-shape dates back to Roman times, provides a concrete context for examining the environmental, energetic, and social dimensions of water management. This framework enables the definition of a scenario to address major threats, including river flooding, marine flooding, and the phenomenon of relative subsidence (Figure 16).

Figure 16. *M. D'Oria, Diagrams of the Main Phenomena Currently Threatening the Lower Fiulian Plain Area, 2025*



At the environmental level, existing water bodies can be interpreted both as precious natural reserves, able to proliferate and nurture biodiversity reservoirs, and as dynamic bodies, whose limits –embankments, riverbanks, dams, banks– can be expanded through the introduction of buffering zones capable of accommodating periodic hydraulic fluctuations while simultaneously supporting processes of ecological re-colonization by new wildlife forms. Seven principal rivers originate from the *linea delle Risorgive* and traverse the plain north-south toward the Grado and Marano lagoons, giving rise to as many linear ecological systems along their course. In addition, the extensive drainage network (Figure 17), spread throughout the plain, constitutes a latent reserve of biodiversity, a potential subsystem that could be strengthened and interconnected through hedges, rows of trees, wooded islands and clearings. Through systematic interventions on both natural and artificial hydraulic margins, the resulting scenario configures a territorial system of buffers and expanded areas able to host water –also by taking advantage of the peculiarly similar altitudes of the Plain and the waters (Figure 18)–, for different time durations, simultaneously mitigating the hydraulic risk and reinforcing the ecosystemic ecological continuity.

Figure 17. *M. D'Oria, Map of Natural Water Systems and the Anthropogenic Hydraulic System, with its Division into Mechanical Basins Served by Water Pumps, 2025*

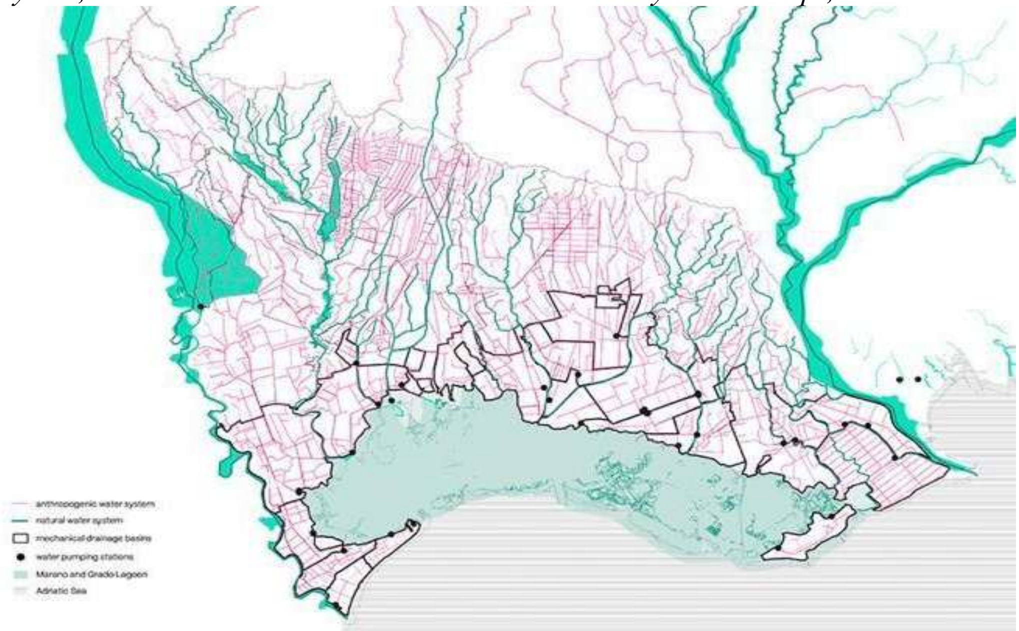
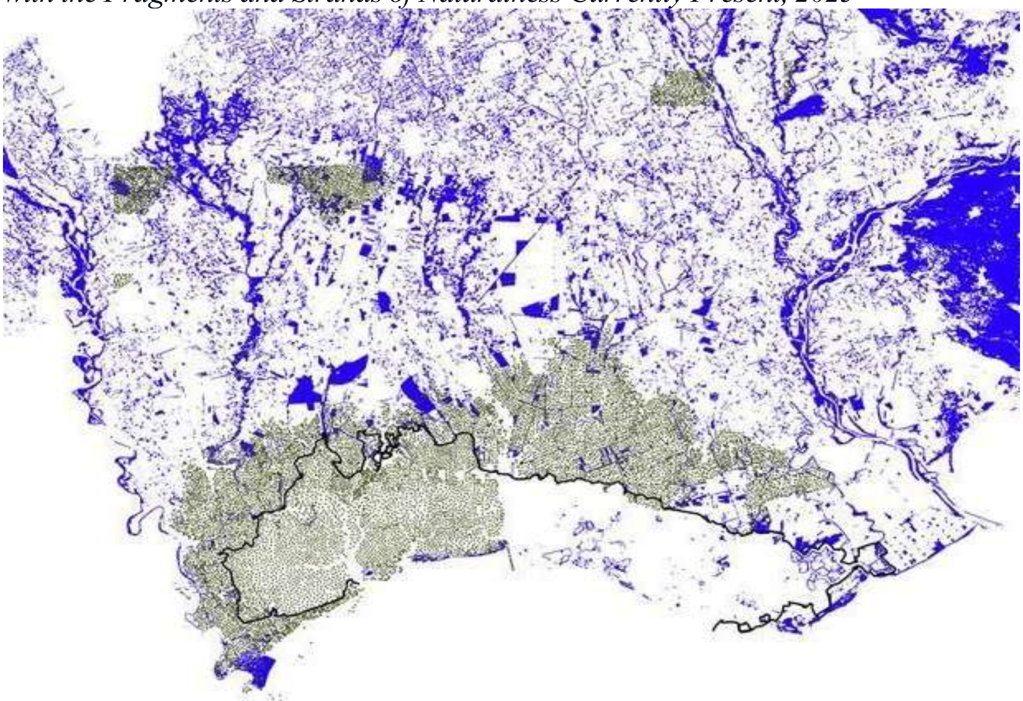


Figure 18. *M. D'Oria, Map of the Altitudes of the Lower Fiulian Plain Intertwined with the Fragments and Strands of Naturalness Currently Present, 2025*



At the energetic level, water is reinterpreted as a proper energetic infrastructure. Its flows, channeled, regulated and accelerated, can once again generate energy, reverberating one of its ancient functions. At a more capillary scale, a vast range of technologically advanced devices could be integrated within the territory to produce new forms of sustainable energy. Also, for the Lower Fiulian Plain the energetic issue is particularly pressing, especially in the contemporary condition, when climate change is highly alterating these territories, determining a series of shifts in both their production logics and crop typologies, demanding new adaptive strategies. Interpreting this landscape as a whole continuous productive fabric may support the redefinition of its energetic asset. Former drainage and irrigation infrastructures become integrated components of a post-fossil territorial machine – converting the inherited productive infrastructures into new energetic engines (Figures 19-20).

Figure 19. *M. D'Oria, Diagrams on the Interventions on the River Banks, 2025*

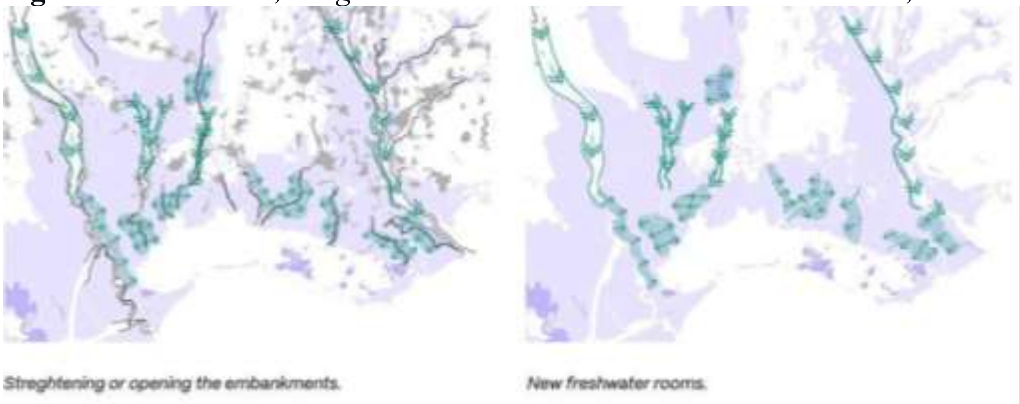
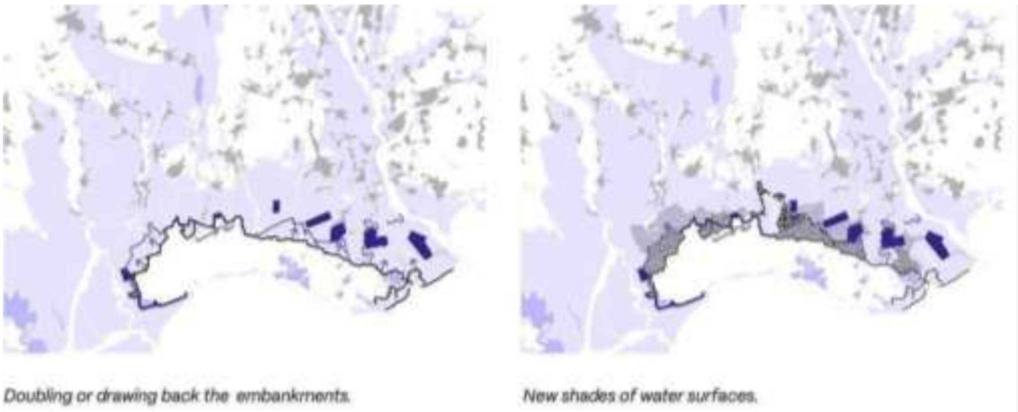


Figure 20. *M. D'Oria, Diagrams of the Interventions on the Lagoon Embankments, 2025*

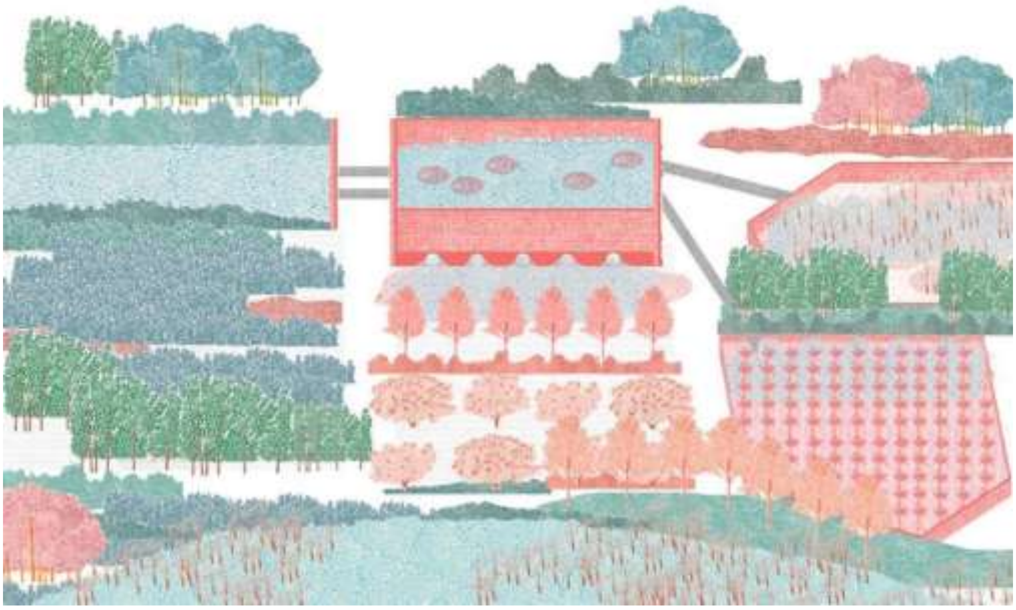


Lastly, recalling and resonating with the concept of the hydro-social territory, water operates also as a social infrastructure, for which the Low Fiulan Plain presents two important elements. Firstly, its very formation is inseparable from centuries of human labor: its ground constitutes a sedimented and stratified archive of social and human practices that have been superimposed upon each other progressively, according to the advancement of reclamation technologies. This grounded social memory recalls not only archetypal water machines, water-connected professions, as well as legends and popular narratives, but constitutes a fundamental vital component that can support renewed forms of crossing, experiencing, and inhabiting the territory.

Moreover, any further phase of hydraulic reorganization would not represent a rupture, but an additional phase in a long-standing process of anthropogenic metamorphosis. Furthermore, a further re-organization of the Plain would not have a huge impact on the existing settlements, due to the very nature of its consistency. The typical settlements and, thus, inhabiting forms rooted within this context, differ radically from the urban ones and also from those of small villages, and are based on the farmhouse. This particular settlement embodies a distinct concept of community, centered around small and isolated centers, and is deeply intertwined with the agricultural fields and their labor. Consequently, architectural interventions remain punctual and localized.

Within this category of intervention, the project identifies approaches operating on vast bodies of water –lagoons, rivers, dikes, deltas–, activating transversal and transcalar tactics aiming at strengthening hydraulic risk prevention while preparing the ground for new integrated ecologies between humans, non-humans, "nature", energy, and settlements. By interpreting water as a strategic environmental, energetic, and social infrastructure, they endure gradual processes of territorial restructuring, rebalancing threatened equilibria, and supporting new models of coexistence (Figure 21).

Figure 21. *M. D'Oria, Going with the Flow: Dealing with Different Water Flows, 2025*



Climatic and Sensorial

The second category concerns the design of micro-climatic and micro-sensorial ambients within this specific context. This approach engages a more invisible and less tangible dimension of water: not only its capacity to regulate climatic comfort, but also its ability to generate experiential and sensorial conditions when carefully orchestrated through design. On the one hand, this category addresses how water's properties –humidity, evaporation, thermal inertia– can be channeled and converted into operative design(ed) elements. On the other, it focuses on the experiential and sensorial dimension this resource can materialize when treated with the proper care and organized according to the beneficial effects it triggers under certain conditions. In this sense, hydro-social territories concern not only energetic and ecological issues, but also, foremost, much more intangible social practices that can be supported and reinforced thanks to the visible and invisible presence of water. By extending the operative field of design into the atmospheric dimension, differentiated climatic micro-regions are modulated, enhancing the climatic and environmental comfort of humans and non-humans (Figure 22).

Figure 22. *M. D'Oria, Imagining New Possible Sections for the Lower Fiulian Plain, 2025*

This second category operates at an intermediate scale between territorial infrastructure and punctual architectural devices. Strictly connected to the definition of wider macro-territorial systems, constituting its very framework and condition of existence and "specialization" –salty or freshwater, marshland wetlands or permanent grassland, humid or dry climates–, it triggers intermediate-scalar transformations, operating on specific areas and managing water resources to configure heterogeneous ecological corridors and biodiversity-friendly micro-areas.

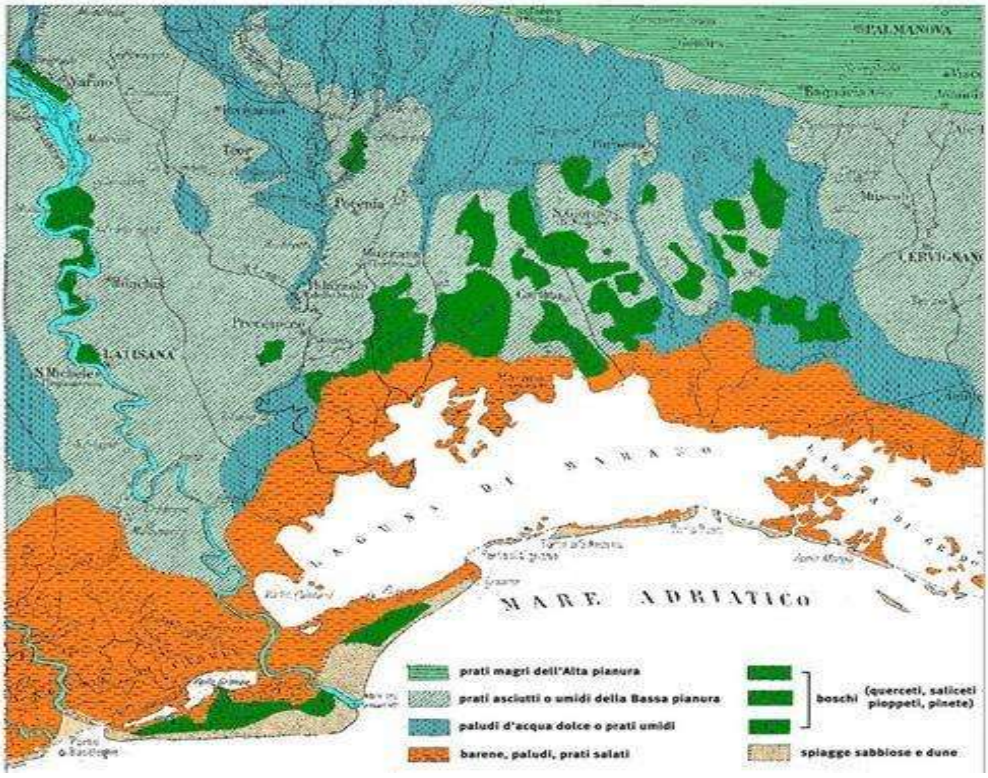
To explore this design approach and test it within the Lower Fiulian Plain, it is necessary to briefly observe the specific interactions between water, vegetation, and anthropogenic pressures that characterize this landscape. The territory consists of a complex heterogeneous mosaic of micro-landscapes, structured around two defining aspects. The first is the close strong dependence on the water presence, both in quantitative terms –soil saturation, groundwater depth, atmospheric humidity– and qualitative terms –particularly the distinction between freshwater and saline systems. The second is the often conflicting tension between "natural" processes, which persists in the form of long strands or residual "wilderness" areas, and the anthropogenic logics of control and exploitation, that have progressively stratified across the landscape. The distribution and variety of vegetation patterns reflect this relationship. In areas where water bodies are present, dense and diffuse vegetation systems emerge, composed of trees, undergrowth, and humid areas. The vegetation modulates itself, harmonizing with the gradation and variation of water's presence, in all its states:

liquid, solid, and gaseous, introducing patterns adapted to the different microclimatic conditions. This results in a layered and articulated landscape composed of lagoons, riparian areas, marshes, forests, and agricultural areas, all of which are now threatened by climate change and require urgent protection and reinforcement strategies.

In this sense, the design of climatic and sensorial clusters is a strategy already embedded in the DNA of the Lower Fiulian Plain. The scenario reinforces the landscape connotations already latent in the area through processes of modulation and gradation. By working through modulation and gradation, the analytical framework demonstrates that this approach introduces within this territory processes of "natural" re-colonization, while simultaneously configuring new spaces for its dispersed community to engage in social practices. By intervening in small-scale areas, the project embodies the very tool through which these microclimatic distributions can be remodeled and re-shaped, generating more hospitable conditions for the inhabitation and coexistence of new forms of living, both for humans and non-humans.

Figure 23. *Silva Lupanica of the Lower Fiulian Plain, 1865*

Figure 24. *D. Feruglio, Territorial Planning Scheme of the Lower Fiulian Plain, 1926*



A crucial element in structuring such a system of gradual climatic zones is the presence of an essential ecological element characterizing this context: the lowland forest known as *silva lupanica*. Historical mappings of this lowland forest, as depicted by the Paiero map (1965), show its once-extensive-configuration (Figure 23). Successive phases of exploitation –firstly under the Republic of Venice to supply the timber for expanding cities and for its Arsenale, and then by the 20th-century land reclamation campaign – gradually replaced the *silva* with crops (Figure 24). Today, this amphibious and archaic forest has been reduced to a scattered archipelago of few isolated strands and fragments, covering approximately 700 hectares. The establishment of differentiated climatic zones supports the reconnection of these fragments, reinforcing ecological continuity and resilience (Figures 25-26).

Figure 25. *M. D'Oria, Diagram of the Progressive Colonization of the Weakened River Banks by the Post-Silva Lupanica, 2025*

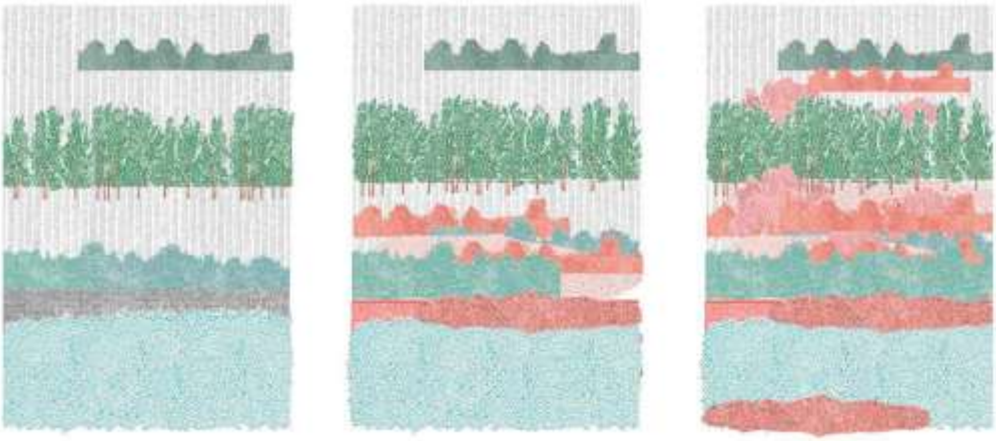


Figure 26. *M. D'Oria, Diagram of the Progressive Recovery of the Agricultural Soil through Specific Arboriculture, 2025*

Micro and Diffused Systems of Amphibious Artefacts

The third category identified through the case studies marks a further scalar shift. It consists of an archipelago of smaller and architectural-scale dispositifs and interventions that endure punctual, yet tactical and crucial, operations at the local scale. Although initially derived from the contextualized urban case of Dora Park, these tools reveal relevant potentials when transposed to rural and environmental contexts. Their main sphere of action involves the issue of regeneration and revaluation of existing heritage, whether natural or anthropogenic. Operating at a reduced scale, these design interventions activate processes of reuse and recovery of existing architectural structures and public spaces, enduring an operation whose results can be understood in two complementary ways. First, they function as minimum intervention units: small and adaptable elements that can be reiterated and declined within much more vast areas, acting as localized activators of regenerative and reparative processes. Second, when deployed as a system, they can construct a diffuse and spread network of socially infrastructure spaces, capable of supporting pedagogical and educational activities while preserving and reactivating the social memory embedded in historic hydraulic and architectural heritage artifacts.

Within the Lower Fiulian Plain, the introduction of these minimum intervention units, together with the recovery of existing structures, reinforces the visibility and tangibility of water, underlying its vital function for environmental balance, renewable energy production, and social practices and identity.

On the first, environmental, level these objects embody ecological connectors and wildlife strategic passages that permits the functioning of the whole system, as in the case of the accurate maintenance of the riverbanks and the banks of the canals, of the realization of water collection tanks and purification systems or, moreover, of tiny structures built to allow wildlife to cross or to create micro-habitats that encourage them to stop and reproduce. In this sense, the realization of these particular interventions, would guarantee the correct functioning of this hydro-social landscape macro-system, interpreted as a whole, supporting it through a micro and diffused infrastructure of water, energy machines, and multi-species mobility (such as bridges, paths, wildlife confined areas, renewed structures for living). On an energetic level, these objects convert into small and diffuse engines that, exploiting the movements of water and its variations, produce new forms of sustainable energy nurturing locally the settlement as well as the productive system: small machines located into the calm basins or in the same channels, sustainable hydroelectric power plants, water pumping systems, to name a few. Moreover, this diffuse operation would reinforce the specific elements and identitarian structures hosted by this territory, recovering its stratified memory through the restoration of its amphibious archaeology, thus reinforcing its identity. Finally, the realization of a hybrid filigree of minute ancient and new artifacts, by revealing and underscoring the tangible and vital presence of water, would empower social practices of care and re-educative processes that would further solidify the already existing bond between humans and this territory.

Toward an *Ecotechnic* Era

Water has established an enduring relationship between humans, energy, and landscape, a relationship that has formed a heterogeneous system of landscapes in which it has originated different shapes of mutual connections, interdependencies, and interferences. Observed within the contextualized territory of the reclamation landscapes, this relation assumes even broader and more complex shades, due simultaneously to the very *terraqueous* consistency of these territories and their anthropogenic origins –derived from constant processes of modeling to conquer land from water to install settlements and productive fields.

This work positions outside the current mainstream interpretation of these territories as "landscape machines", as an interpretation that separates strictly the technological, cultural, ecological, and social spheres they involve. Employing the concept "hydro-social territory", the research draws a critical reasoning on the complexity of intervening in and interacting with the amphibious territories, which are bound by a "multi-scalar network in which humans, water flows, ecological relations, hydraulic infrastructure, financial means, legal-administrative arrangements, and cultural institutions and practices are interactively defined, aligned, and mobilized through epistemological belief systems, political hierarchies, and naturalizing discourses" (Boelens et al. 2016, p. 2).

This reinterpretation aims to establish a new territorial and cultural framework in which all the processes at the core of territorial functioning must be integrated as part of a comprehensive system. In this sense, energy production, ecological coexistence, and inhabitation practices are not thematic issues to be solved individually, but interconnected spheres of a unique territory, whose design, also through the adoption of trans-disciplinary assets, has to be ambitiously confronted simultaneously. Therefore, the oddly named "landscape machines" become metabolic systems whose functioning permits the integration of multiple processes: from food production to the accumulation of energy, from the repairing of ecological infrastructures to the favoring of new colonization by forms of wildlife, and finally, from the strengthening of the cultural identity to the formulation of new forms of settlement and coexistence.

These observations require a first significant shift, which can be further developed and explored in the future: the passage from the landscape machine to the environmental machine. Building on this general framework, a deepened focus on the peculiar territories of agricultural reclamation has been developed, firstly investigating three significant case studies and then projecting their deployed strategies within the specific contextualized scenario of the Lower Fiulian Plain, in Italy.

It has been noticed that the reclamation landscapes appear to simultaneously meet the meaning and values of hydro-social territories –interfaces among society, technology, and nature – and the potentialities of being used as experimental grounds to rebalance the threatened relationship between nature, humans, production, and sustainable energies. Therefore, applying, even through a speculative approach, a complex system of multi-scalar strategies, it has been drawn an example of how the reclamation landscapes could be reinterpreted in ecological terms, configuring sustainable and resilient territorial structures, reinterpreting reclamation today as a complex system of practices capable of relaunching climatic, ecological and social interaction emergency cycles.

In this sense, the reclamation landscape constitutes today, in the epoch marked by mainstream debates on urban reforestation, a concrete and still latent potential for defining a new post-fossil environmental machine that converts its old productive infrastructures into new sustainable energy engines and ecological catalysts.

Therefore, if the core research question focused on the possible formulation of a fourth, contemporary phase of technological development –following the eotechnic, paleotechnic, and neotechnic phases delineated by Lewis Mumford– a possible formulation could be the *ecotechnic era*. The formulation of this concept, still scarcely adopted within the disciplinary debate, comes from John Michael Greer who describes this era as the alignment of technological development with ecological limits. A close reading of Greer's argument reveals a significant shift in the epistemological stance from which the relationship between humans and technology is interpreted. Whereas Lewis Mumford elaborates a genealogy of technological eras from an explicitly anthropogenic viewpoint—focusing on how technological systems shape, and are shaped by, social organization, productive practices, and cultural imaginaries—Greer examines technology from a broader ecological perspective in which humanity is repositioned as one species among others, embedded within natural systems, projecting forward toward a future epistemology in which technological practice is re-situated within planetary processes.

The *ecotechnic era*, where all the main humans and non-humans existential issues would be integrated –food, home, work, energy, community, culture, and science– by operating an exit from a much more human-influenced perspective, stresses the search for a rebalanced combination between the technosphere and the biosphere, between the technological elements of the machines and that, natural, of the ecosystems, inviting to experiment with systems capable of providing self-sustaining cycles for preparing the ground for new multi-species coexistence.

These observations, combining the reinterpretation of the reclamation landscape as a post-fossil environmental machine and the intention of adhering to the incoming new ecotechnic era, need to be posed at the basis for drawing a renewed and updated, constantly mutating, "ritratto" (portrait) of these hydro-social territories.

If the "portrait" found on the maps of the past is an image of the table itself, of the flat, continuous, homogeneous, and isotropic extension that serves as the archetype of the modern state" (Farinelli 2009, p. 87), a flat representation that has been exploited to represent, through an anthropogenic posture, the conquered lands from water, its representation and its very meaning have to be subject to a profound shift too, within the very aim of this representational process. The hydro-social territories refuse any representation as human-controlled and confined surfaces, instead needing to be drawn and interpreted as open and mutable systems that constantly rebalance the weights within the relations between humans, the environment, and energy, seeking the formulation of new ways of living and co-living together.

Impacts and Research Results

The work presented here is part of a research project developed between July 2024 and June 2025 within the Department of Civil-Environmental Engineering and Architecture at the University of Trieste (Italy), entitled *Re-inhabiting the Friulian Deserts*. The work has been presented at numerous national and international conferences. In particular, some important results achieved are highlighted:

- Establishment of a collaborative relationship and dialogue with the Consorzio di Bonifica della Venezia Giulia (Land Reclamation Consortium of Venezia Giulia), within which the research grant has led to an agreement for the creation of an internship programme. This structure is a point of reference for the area under study, both in terms of its administrative and maintenance functions for part of this territory and as an important archive and custodian of its historical memory.
- The survey developed alongside the research also gave rise to critical reflection on the technological device of "filare", understood as an element capable of weaving new ecologies in urban and rural areas. This contribution was presented at the conference 'Arbosfera. Rethinking urban space through the forest' (University of Naples Federico II, January 2025) and later became

a disciplinary contribution to the PRIN (Project of National Interest, PNRR 2022) project "RighTT, The Right Tree in the Right Town. Urban Forestry for People".
- Definition of a further research project "Microstorie del paesaggio della bonifica" ("Microstories of the reclaimed landscape") selected from the University of Trieste (November 2025) to be presented for future fundings by the Regione Autonoma Friuli Venezia Giulia, in particular for the call CAR2go! "proposals to support cultural projects aimed at promoting the intangible cultural heritage of the Friuli Venezia Giulia Region".

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Authorship Attributions

The authors fully agree on the content, but it should be noted that the paper was structured as follows: Conceptualisation - Mariacristina D'Oria, Thomas Bisiani; Investigation - Mariacristina D'Oria; Methodology - Thomas Bisiani; Mariacristina D'Oria; Writing – original draft - Mariacristina D'Oria: Intertwined Bodies: Humans, Water, Ground, and Energy; Amphibious Geographies: Hydro-Social Territories Seeking Reinterpretation; Retracing a Taxonomy of Strategies to Configure Renewed Hydro-Social Territories; Exploring the Transformative Potentials of Designing from the Lens of the Hydro-Social Territories: The Application to the Specific Case Study of the Lower Fiulian Plain; Toward an Ecotechnic Era; Writing – review - Thomas Bisiani; Supervision and validation - Thomas Bisiani.

References

Boelens R, Hoogesteger J, Swyngedouw E, Vos J, Wester P (2016) Hydrosocial territories: A political ecology perspective. *Water International* 41(1): 1–14.

Ciriacono S (1999) *Acque e agricoltura. Venezia, l'Olanda e la bonifica europea in età moderna*. (Water and Agriculture: Venice, the Netherlands, and European Land Reclamation in the Modern Age). Milano: FrancoAngeli.

Corner J (1999) *Recovering Landscape: Essays in Contemporary Landscape Architecture*. Princeton Architectural Press.

Farinelli F (2007) *L'invenzione della Terra*. (The invention of the Earth). Palermo: Sellerio Editore.

Farinelli F (2009) *La crisi della ragione cartografica*. (The crisis of cartographic reason). Torino: Piccola Biblioteca Einaudi.

Greer JM (2009) *The ecotechnic future. Envisioning a post-peak world*. Canada: New Society Publishers.

Karpouzoglou T, Vij S (2017) Waterscape: a perspective for understanding the contested geography of water. *WIREs Water* 4(3): e1210.

Linton J, Budds J (2014) The hydrosocial cycle: Defining and mobilizing a relational-dialectical approach to water. *Geoforum* 57: 170–180.

Meyer EK (2008) Sustaining beauty – the performance of appearance: Can landscape architects insert aesthetics into our discussions of sustainability? *Journal of Landscape Architecture* 9(10): 6–23.

Mumford L (1943) *Technics and Civilization*. London: Routledge & Kegan Paul Ltd.

Roncken PA, Stremke S, Paulissen MPCP (2011) Landscape Machines, productive nature and the future sublime. *Journal of Landscape Architecture* 6(1): 68–81.

The Editorial Board of Ardeth (2023) From Prometheus to Epimetheus. In *Ardeth (Energy Landscapes)*, no. 13. Available at: https://journals.openedition.org/ardeth/4123.

Todd J, Todd NJ (1994) *From Eco-Cities to Living Machines: Principles of Ecological Design*. North Atlantic Books.