

Predicting the Future of Clean Energy: How Machine Learning Can Accelerate SDG 7

Introduction: The Clean Energy Challenge

In 2015, world leaders committed to ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030 through the United Nations Sustainable Development Goal 7. Yet today, billions still lack access to clean energy, and the transition from fossil fuels remains one of humanity's greatest challenges.

The question isn't just "Can we transition to renewable energy?" but rather "How quickly can we do it, and what factors will make the difference?"

This is where Artificial Intelligence enters the conversation.

The Problem: Why Countries Struggle with Renewable Energy Adoption

The Current Landscape

As of 2020, renewable energy accounts for approximately 29% of global electricity generation. While this represents progress, the pace of adoption varies dramatically between countries. Some nations like Norway and Iceland generate over 90% of their electricity from renewables, while others remain heavily dependent on fossil fuels.

Key Challenges

- Unpredictable Transitions:** Countries struggle to forecast their renewable energy adoption rates, making it difficult to plan infrastructure and investments.
 - Resource Allocation:** Without predictive insights, governments can't effectively allocate budgets for solar panels, wind farms, or hydroelectric dams.
 - Unrealistic Targets:** Many countries set ambitious renewable energy goals without understanding the factors that influence adoption success.
 - Lack of Data-Driven Insights:** Policymakers often lack tools to understand which interventions will have the greatest impact.
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The Solution: Machine Learning for Energy Forecasting

Our Approach

I developed a **Renewable Energy Adoption Predictor** using supervised machine learning to forecast renewable energy adoption rates based on historical data from 176 countries over 20 years (2000-2020).

How It Works

The system analyses multiple factors that influence renewable energy adoption:

Economic Indicators:

- GDP per capita
- GDP growth rate
- Energy intensity of the economy

Energy Infrastructure:

- Current electricity from renewables
- Fossil fuel electricity generation
- Nuclear energy capacity

Social Factors:

- Population with access to electricity
- Access to clean cooking fuels
- Population density

Geographic Features:

- Country location (latitude/longitude)
- Land area
- Natural resource availability

Environmental Metrics:

- CO2 emissions per capita
- Low-carbon electricity percentage

The Machine Learning Pipeline

Step 1: Data Preprocessing

- Cleaned 3,649 data points across 21 features
- Handled missing values using median imputation
- Applied standard scaling for numerical features
- Split data into 80% training and 20% testing sets

Step 2: Model Training We compared three supervised learning algorithms:

1. **Linear Regression:** A baseline model providing interpretability
2. **Random Forest Regressor:** An ensemble method that handles non-linear relationships
3. **Gradient Boosting Regressor:** Advanced boosting algorithm for maximum accuracy

Step 3: Model Evaluation Each model was evaluated using:

- ♦ Mean Absolute Error (MAE)
 - ♦ Root Mean Squared Error (RMSE)
 - ♦ R² Score (percentage of variance explained)
 - ♦ 5-fold Cross-Validation
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The Results: What We Discovered

Model Performance

After rigorous testing, the **Random Forest Regressor** emerged as the best-performing model, achieving:

- High R² score indicating strong predictive power
- Low prediction errors on unseen country data
- Robust cross-validation results

Key Insights

Most Influential Factors for Renewable Energy Adoption:

1. **Current Renewable Infrastructure:** Countries with existing renewable energy capacity are more likely to expand it further.
2. **Economic Development (GDP per capita):** Wealthier nations have more resources to invest in clean energy infrastructure.
3. **Access to Clean Cooking Fuels:** This indicator reflects overall energy access and infrastructure development.
4. **Energy Intensity:** Countries with higher energy efficiency tend to adopt renewables faster.
5. **Geographic Location:** Solar and wind potential vary significantly by latitude and climate.

Real-World Applications

For Policymakers:

- ♦ Set evidence-based renewable energy targets
- ♦ Identify which factors to prioritize for maximum impact

Allocate budgets more effectively across clean energy initiatives

Track progress against predictions and adjust strategies

For International Organizations:

- Identify countries that need additional support
- Prioritize resource allocation for development aid
- Monitor global progress toward SDG 7 targets

For Investors:

- Assess renewable energy investment opportunities
 - Evaluate country-specific risks and opportunities
 - Make data-driven decisions about clean energy projects
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The Impact: How This Contributes to SDG 7

Direct Contributions

- 1. Accelerating Energy Transition** By providing accurate predictions, countries can move faster with confidence in their planning.
- 2. Ensuring Affordability** Better planning reduces waste and keeps energy costs manageable for populations.
- 3. Universal Access** The model helps identify barriers to electricity access and renewable adoption in underserved regions.
- 4. Sustainability** Data-driven decisions lead to more sustainable long-term energy policies.

Measurable Outcomes

- **Better Resource Allocation:** Countries can invest in the most impactful renewable energy projects
 - **Reduced Carbon Emissions:** Faster renewable adoption means lower greenhouse gas emissions
 - **Energy Security:** Diversifying energy sources reduces dependence on fossil fuel imports
 - **Economic Growth:** Clean energy sector creates jobs and stimulates innovation
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Ethical Considerations: Building Responsible AI

Addressing Bias

Challenge: Historical data may favour developed countries with better data collection systems, potentially creating biased predictions that disadvantage developing nations.

AI for Clean Energy – by Peter Kamau Mwaura

Our Approach:

- Included economic, geographic, and social factors to account for different starting points
- Used median imputation rather than dropping data from countries with missing information
- Validated model performance across diverse regions
- Made the model transparent and explainable

Fairness and Equity

Principle: AI should not perpetuate existing inequalities in energy access.

Implementation:

- The model considers each country's unique context
- Features include both economic capacity and infrastructure gaps
- Predictions account for different development stages
- Results are meant to guide, not dictate, human decision-making

Data Privacy and Transparency

- All data used is publicly available and aggregated at country level
- No individual or corporate data is involved
- Model methodology is open-source and reproducible
- Results are interpretable and explainable to non-technical stakeholders

Sustainability of AI Itself

Machine learning models consume energy. We addressed this by:

- Using efficient algorithms (tree-based methods over deep learning where appropriate)
- Training once and deploying for multiple predictions
- Providing tools that prevent wasteful energy investments
- Net positive impact: Better energy planning saves far more energy than the model consumes

Technical Implementation: Tools and Technologies

Technology Stack

Programming Language: Python 3.8+

Core Libraries:

- **pandas:** Data manipulation and analysis
- **NumPy:** Numerical computing
- **scikit-learn:** Machine learning algorithms and evaluation
- **matplotlib & seaborn:** Data visualization

Machine Learning Techniques:

- Supervised Learning (Regression)
- Ensemble Methods (Random Forest, Gradient Boosting)
- Cross-Validation for model robustness
- Feature Importance Analysis

Development Environment

- **Google Colab / Jupyter Notebook:** For interactive development
- **GitHub:** Version control and collaboration
- **Kaggle:** Dataset source and community

Why These Choices?

1. **Python:** Industry standard for data science with extensive ML libraries
 2. **Scikit-learn:** Robust, well-documented, and production-ready algorithms
 3. **Random Forest:** Handles non-linear relationships and provides feature importance
 4. **Open Source:** All tools are free and accessible to everyone
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Lessons Learned: Challenges and Solutions

Challenge 1: Missing Data

Problem: Many countries had incomplete data, especially developing nations and conflict zones.

Solution: Used median imputation strategically, ensuring we didn't drop entire countries from analysis.

Challenge 2: Feature Selection

Problem: With 21 features, some were redundant or less relevant.

Solution: Applied domain knowledge about energy systems and used feature importance analysis to identify key predictors.

Challenge 3: Model Interpretability

Problem: Complex models can be "black boxes" that policymakers don't trust.

Solution: Chose Random Forest for its balance of accuracy and interpretability, and provided feature importance visualizations.

Challenge 4: Avoiding Oversimplification

Problem: Energy transitions involve complex political, social, and cultural factors beyond data.

Solution: Positioned the model as a decision-support tool, not a replacement for human judgment and local expertise.

Future Enhancements: Taking It Further

Phase 2: Real-Time Predictions

Goal: Integrate live data from World Bank and UN databases for up-to-date predictions.

Implementation:

- API connections to data sources
- Automated retraining pipeline
- Dashboard for real-time monitoring

Phase 3: Interactive Web Application

Goal: Make the tool accessible to policymakers worldwide.

Features:

- User-friendly interface for non-technical users
- Country-specific recommendation engine
- Scenario analysis ("What if we increase clean fuel access by 20%?")
- Downloadable reports for policy briefs

Technology: Streamlit or Flask for deployment

Phase 4: Multi-SDG Integration

Goal: Expand beyond SDG 7 to show connections with other goals.

Connections:

- SDG 13 (Climate Action): Link renewable energy to carbon reduction
- SDG 8 (Decent Work): Model job creation in clean energy sector

SDG 11 (Sustainable Cities): Urban energy planning

- SDG 3 (Health): Reduced air pollution from clean energy

Phase 5: Deep Learning Enhancement

Goal: Explore neural networks for time-series forecasting.

Approach:

- LSTM networks for multi-year predictions
 - Attention mechanisms to identify critical time periods
 - Ensemble of traditional ML + deep learning
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Call to Action: How You Can Contribute

For Fellow Developers

1. **Fork the GitHub Repository:** Improve the code, add features, fix bugs
2. **Test with Different Datasets:** Validate the approach with regional data
3. **Build Complementary Tools:** Create visualization dashboards or mobile apps
4. **Contribute to Documentation:** Help make the project more accessible

For Policymakers and Organizations

1. **Test the Model:** Use it for your country or region's energy planning
2. **Provide Feedback:** Share what works and what needs improvement
3. **Share Data:** Contribute additional datasets to improve accuracy
4. **Adopt the Insights:** Let data guide your renewable energy strategy

For Researchers and Students

1. **Validate the Approach:** Conduct peer review and academic analysis
 2. **Extend the Research:** Explore related problems in sustainability
 3. **Teach with It:** Use this project in ML courses and workshops
 4. **Publish Findings:** Write papers on AI for sustainable development
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Conclusion: AI as a Force for Good

The transition to clean energy is not just a technical challenge—it's a moral imperative. By 2030, we must ensure that everyone has access to affordable, reliable, and sustainable energy. This isn't just about meeting UN

targets; it's about:

- **Fighting climate change** and preserving our planet for future generations
- **Improving health** by reducing air pollution from fossil fuels
- **Creating economic opportunities** in the growing clean energy sector
- **Ensuring equity** so that everyone benefits from modern energy access

Machine learning offers powerful tools to accelerate this transition. But technology alone isn't enough. We need:

- **Ethical AI development** that prioritizes fairness and transparency
- **Collaboration** between data scientists, policymakers, and communities
- **Human-centred design** that puts people's needs first
- **Continuous learning** as we gather more data and refine our models

This project demonstrates that AI can be more than a business tool—it can be a catalyst for sustainable development and social good. By predicting renewable energy adoption, we're not just making forecasts; we're helping write a better future.

Key Takeaways

1. **Machine learning can predict renewable energy adoption** with high accuracy using historical data and multiple influencing factors.
2. **Economic development, existing infrastructure, and social factors** are the strongest predictors of renewable energy success.
3. **Ethical AI development is crucial** to ensure predictions don't perpetuate inequalities or disadvantage developing nations.
4. **This approach is scalable and replicable** for other SDGs and sustainability challenges.
5. **Data-driven decision-making** enables faster, more effective progress toward global clean energy goals.

Resources and Links

- **GitHub Repository:** <https://github.com/Phitah02/AI-Machine-Learning-Assignment>
- **Live Demo:** [Coming Soon]
- **Dataset Source:** [Kaggle Link](#)
- **UN SDG 7 Information:** <https://sdgs.un.org/goals/goal7>
- **Contact:** daudipeterkamau@gmail.com | [LinkedIn Profile](#)

About the Author

Peter Kamau Mwaura is a data scientist and machine learning enthusiast passionate about using AI for social good. This project was developed as part of the PLP Academy AI/ML program, combining technical skills with a commitment to sustainable development.

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"The future of energy is clean, accessible, and powered by intelligent systems. Together, we can make SDG 7 a reality."

🌐 Let's code for a better world! ✨

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