Austrian Council
on Robotics and
Artificial Intelligence

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OPPORTUNITIES

for Robotics and Artificial Intelligence to Address Climate Change and Protect the Environment

Preface

Climate change poses an existential threat to humanity. Moreover, increasing pollution and other unsustainable human practices exacerbate the damages to an already stressed environment. Hence, there is urgent demand for action to avoid a catastrophic climate crisis. If used in the right way, tools from artificial intelligence (AI) and robotics can be harnessed to address climate change and implement sustainable societal processes. The aim of this document is to highlight emerging opportunities for leveraging technological advances in AI and robotics that can lay the foundations for a sustainable future.[1] The document introduces a list of potential application scenarios for robotics and AI in the areas of climate change and environmental protection. It also provides recommendations and considerations of how to develop and deploy such systems within the Austrian ecosystem of research, technology, and innovation.

[1] In accordance with ACRAI's White Paper "Shaping the Future of Austria with Robotics and Artificial Intelligence", November, 2018.

What is an AI System?

"AI enables computers and other automated systems to perform tasks that have historically required human cognition and human decision-making abilities. Research in AI is therefore concerned with the understanding of the mechanisms underlying thought and intelligent behavior and their implementation in machines. The full AI endeavor is inherently multidisciplinary, encompassing the research necessary to understand and develop systems that perceive, learn, reason, communicate, and act in the world; exhibit flexibility, resourcefulness, creativity, real-time responsiveness, and long-term reflection; use a variety of representation or reasoning approaches; and demonstrate competence in complex environments and social contexts."[2]

We distinguish two types of AI systems: (i) those that are "embodied" by means of a physical system, and (ii) those that do not have such an embodiment. Embodied AI systems typically have sensors that provide the system with measured values of aspects of its environment and actuators that allow it to interact with the environment with typical examples being robots and various types of cyber-physical systems. In contrast, disembodied AI systems do not have an external embodiment outside of their computational system but exist as software programs. The two types of systems have different capabilities, and thus different potentials for environmental protection and climate change mitigation and adaptation.

[2] Definition of AI taken from National Science Foundation, 2020. National Artificial Intelligence (AI) Research Institutes, Program Solicitation, NSF 20-604.

Fields of Application

Austria's strategy for climate change mitigation and adaptation has the goal of reducing greenhouse gas emissions to net zero by 2040.[3] Here we will illustrate a number of promising applications that can aid in achieving this goal.[4]

Precision Agriculture

Robots can be used in many areas of agriculture, especially in plant cultivation, such as planting and harvesting, as well as in plant care such as fertilization, weed and pest control. They can also be deployed in livestock farming, e.g., for milking cows or detecting pest infestations or diseases in animal flocks. The aim of precision agriculture is to use less water and fertilizer, require fewer pesticides (possibly avoiding them altogether through mechanical weeding and natural means of pest control), and minimize energy consumption (e.g., by individually adapting treatment to small areas of a larger field as needed). Early detection of unfavorable developments can reduce the extent of proactive or corrective intervention required (e.g., medication, fertilization, and pest control), which put a strain on the climate and the environment. Fertilizer use, for example, can result in the emission of the potent greenhouse gas nitrous oxide. By enabling a more efficient use of scarce resources like water, precision agriculture can also help farmers adapt to a changing climate. Small-scale agriculture might also benefit from intelligent e-commerce platforms that efficiently balance supply and demand[5], taking all life-cycle costs into account. The idea is to carefully control yields and avoid overproduction through a demand-oriented, flexible agriculture, where crops, vegetables, etc. are planted and harvested based on the demand predicted by AI-supported systems.

3 Federal Chancellery of the Republic of Austria, 2020. Out of a Sense of Responsibility for Austria. Government Programme 2020–2024.

4 A comprehensive overview of climate relevant machine learning applications can be found in Rolnick, D., Donti, P. L., Kaack, L. H., Kochanski, K., et al., 2019. Tackling climate change with machine learning. https://arxiv.org/abs/1906.05433.

5 Alawode, O., 2019, December. Artificial intelligence: matching food demand and supply. Dossier: Artificial intelligence in agriculture. SPORE 195, pp. 28. Technical Centre for Agricultural and Rural Cooperation (CTA).

AI-Supported Manufacturing

The use of AI methods in combination with industrial automation and robotics enables production processes, which can minimize the use of resources (energy, raw materials, water, etc.). With the right incentives, they can reduce CO_2 emissions, while ensuring quality, internationally competitive product costs, and high standards in the workplace (e.g., for human-machine interaction). Furthermore, these technologies contribute significantly to an increase in flexibility of production processes and thus meet the growing demand for product portfolios tailored to specific customer requirements, while avoiding overproduction and thus waste. AI-based automation and robotics is also considered a major enabler for moving certain manufacturing back to Europe (e.g., for clothing and textiles, furniture, electronics, and appliances)[6,7], which can help eliminate unnecessary transport routes, especially in the consumer goods sector, and favor the implementation of more sustainable supply chains.

It is important to stress that human needs and interests must be front and center with any future technology to best enhance human flexibility and creativity. Advanced AI technologies and robotics can facilitate that by adapting to the workers' needs and supporting them (e.g., through training)[8]. This is the concept of the Industry 5.0 approach of the European Union that "moves focus from shareholder to stakeholder value, with benefits for all concerned. Industry 5.0 attempts to capture the value of new technologies, providing prosperity beyond jobs and growth, while respecting planetary boundaries, and placing the wellbeing of the industry worker at the centre of the production process."[9]

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6 Ancarani, A., Di Mauro, C., 2018, July. Reshoring and Industry 4.0: How Often Do They Go Together? IEEE Engineering Management Review 46 (2), pp. 87–96. ISSN: 0360-8581, DOI: 10.1109/EMR.2018.2833475

7 De Backer, K., Menon, C., Desnoyers-James, I., Moussiegt, L., 2016. Reshoring: Myth or Reality? OECD Science, Technology and Industry Policy Papers, No. 27, OECD Publishing, ISSN: 2307-4957, DOI: 10.1787/23074957

8 Müller, J., 2020. Enabling Technologies for Industry 5.0: Results of a workshop with Europe's technology leaders, ISBN 978-92-76-22048-0, DOI: 10.2777/082634

9 Breque, M., De Nul, L., Petridis, A., 2021, January. Industry 5.0 – Towards a sustainable, human-centric and resilient European industry. R&I Paper Series,

Electricity Systems

Renewable Energy Generation

AI can help with integrating more renewable energy sources into the grid by generating more accurate short- and medium-term forecasts of electricity supply from renewable energy sources, for example, based on weather data, historical output, and real-time imagery[10]. As solar photovoltaic panels and wind generators vary in the amount of electricity they produce, such forecasts help with operating the power grid and sustaining larger shares of renewables on the grid. AI is also used in other ways to support power grid operations, for example with intelligent control strategies to use electric loads and storage for additional options to balance supply and demand of electricity.[11] In addition, AI-based remote sensing approaches using satellite imagery can help create complete databases of energy infrastructure, such as decentralized solar photovoltaic systems.[12] Such data were previously often incomplete or not spatially explicit, and can now be used in research, policy making or for grid operations.

Hydropower Plant Operations and Siting

Since more than half of the electricity generated in Austria comes from hydropower (60.2 percent in 2019)[13], which is a low-carbon energy source, operations and

Policy Brief, European Commission, Directorate-General for Research and Innovation. ISBN 978-92-76-25308-2, DOI: 10.2777/308407

10 Perera, K. S., Aung, Z., Woon, W. L. 2014. Machine learning techniques for supporting renewable energy generation and integration: a survey. In International Workshop on Data Analytics for Renewable Energy Integration, pp. 81–96. Springer

11 Antonopoulos, I., Robu, V., Couraud, B., Kirli, D., Norbu, S., et al., 2020. Artificial intelligence and machine learning approaches to energy demand-side response: A systematic review. Renewable and Sustainable Energy Reviews 130, DOI: 10.1016/j.rser.2020.109899

12 Yu, J., Wang, Z., Majumdar, A., Rajagopal, R. 2018. Deepsolar: A machine learning framework to efficiently construct a solar deployment database in the united states. Joule 2 (12), pp. 2605–2617, DOI: 10.1016/j.joule.2018.11.021

13 E-Control Austria, Austrian Energy Measured in Numbers, Key Statistics 2020.

maintenance of these plants is crucial for the Austrian power grid. AI can improve operations of hydropower stations with predictive maintenance, forecast the power output, and help with determining optimal locations for new dams. Predictive maintenance summarizes approaches that analyze large amounts of data collected about facilities in order to predict possible weak spots, a technique that is already applied in hydropower plants.[14] AI-based forecasting techniques can further be used to predict power output from hydropower plants, for example they can help integrate climate variables and geographical features to predict run-of-river hydropower generation.[15] Optimal operation and control of (variable-speed) pumped-storage power plants are essential for meeting the growing demands on stabilizing power distribution grids fed with an increasing amount of renewable energy sources. Advanced automation concepts can ensure safe optimal operation under changing environmental and grid conditions.[16] Lastly, siting new hydropower stations requires complex decision making that needs to satisfy a multitude of stakeholder interests, including environmental effects on existing ecosystems at those sites. This multi-objective optimization problem can also be addressed with computational methods involving AI.[17]

[14] Crate.io, 2019, February, https://crate.io/a/cratedb-machine-learning-and-hydroelectric-power-part-one/

[15] Sessa, V., Assoumou, E., Bossy, M., Carvalho, S., Simoes, S., 2020. Machine learning for assessing variability of the long-term projections of the hydropower generation on a European scale. hal-02507400

[16] Mennemann, J. F., Marko, L., Schmidt, J., Kemmetmüller, W., and Kugi, A., 2020. Nonlinear Model Predictive Control of a Variable-Speed Pumped-Storage Power Plant, IEEE Transaction on Control Systems Technology, DOI: 10.1109/TCST.2019.2956910.

[17] Wu, X., Gomes-Selman, J., Shi, Q., Xue, Y., Garcia-Villacorta, R., Anderson, E., Sethi, S., Steinschneider, S., Flecker, A. and Gomes, C. P., 2018, February. Efficiently Approximating the Pareto Frontier: Hydropower Dam Placement in the Amazon Basin. Proceedings of AAAI, pp. 849–859.

Transport Sector

Road Transportation

AI is applied in several ways to improve road transportation, ranging from applications in individual vehicles (e.g., autonomous driving) to whole systems (e.g., urban traffic optimization). Four strategies can reduce greenhouse gas (GHG) emissions from transportation: (i) reducing transport activity, (ii) improving vehicle efficiency, (iii) electrifying vehicles or using alternative fuels, and (iv) shifting passengers and freight from high- to lower-carbon transportation modes (such as rail). In all these strategies, AI can play an important role.[18]

AI can for example be used for electric vehicle technologies. By analyzing anonymized sensor data received from the cars, the placement of new charging stations can be optimized. Merging this data with power grid data allows for optimization of charging processes and battery storage capabilities (e.g., vehicle-to-grid algorithms) and can not only reduce costs, but also help with integrating renewable energy sources into the electricity grid.

AI is also a key technology in autonomous vehicles (AV) which have been mainly touted as being able to reduce traffic deaths. Yet, they could also be used to improve energy efficiency (e.g., more balanced driving behavior, reduced air resistance with "platooning") or reduce overall traffic (e.g., along-the-way carpooling). In addition, AVs could increase throughput on existing roads, thus eliminating the need to expand highways, everything else being equal.[19]

Furthermore, AI can help with reducing transport activity by optimizing routing and vehicle utilization, thereby eliminating unnecessary trips, for example by avoiding empty runs in logistics. In urban areas, unmanned aerial vehicles (UAVs) could make use of underutilized air space for delivery and replace traditional road-based

[18] Rolnick, D., Donti, P. L., Kaack, L. H., Kochanski, K., et al., 2019. Tackling climate change with machine learning. https://arxiv.org/abs/1906.05433.

[19] But see the Discussion section for caveats regarding the climate change mitigation potential of autonomous vehicles.

means, potentially reducing transport energy consumption.[20] AI is also used in ride-sharing systems to provide real-time information about available resources in close-by locations, which in the case of pooled rides and reduced car ownership could potentially yield GHG emissions savings.

AI can also support unmotorized transportation modes, such as cycling. Similar to the placement of charging stations for electric vehicles, the placement and size (i.e., number of slots) of bicycle sharing stations in a city can be optimized with the help of AI.[21] In a different setting, AI can be applied in station-less bicycle sharing systems, helping to realize short-time forecasting of spatial bicycle distribution, which is important for the planning of efficient and effective rebalancing operations.[22]

Railway Transport Operations and Maintenance

The railway sector is viewed as central to decarbonizing transportation and AI can be used to improve rail operations and maintenance. Current approaches include predictive maintenance on tracks[23] and recognition of rolling stock system failures[24]. Regarding the optimization of rail operations, AI offers a variety of potential

[20] Stolaroff, J. K., Samaras, C., O'Neill, E. R., Lubers, A., Mitchell, A. S. and Ceperley, D., 2018. Energy use and life cycle greenhouse gas emissions of drones for commercial package delivery. Nature communications, 9 (1), pp.1–13.

[21] Kloimüllner, C., Raidl, G. R., 2017, October. Hierarchical Clustering and Multilevel Refinement for the Bike-Sharing Station Planning Problem. Proceedings of the 11th International Conference on Learning and Intelligent Optimization, pp. 150–165, LNCS 10556, ISBN: 978-3-319-69403-0, DOI: 10.1007/978-3-319-69404-7_11.

[22] Ai, Y., Li, Z., Gan, M., Zhang, Y., Yu, D., Chen, W., Ju, Y., 2019, May. A deep learning approach on short-term spatiotemporal distribution forecasting of dockless bike-sharing system. Neural Computing & Applications 31, pp. 1665–1677, DOI: 10.1007/s00521-018-3470-9.

[23] Jamshidi, A., Hajizadeh, S., Su, Z., Naeimi, M., Núñez, A., Dollevoet, R., De Schutter, B., Li, Z., 2018. A decision support approach for condition-based maintenance of rails based on big data analysis. Transportation Research Part C: Emerging Technologies, 95, pp.185–206.

[24] Fink, O., Zio, E., Weidmann, U., 2015, September. Fuzzy Classification With Restricted Boltzman Machines and Echo-State Networks for Predicting Potential Railway Door System Failures, in IEEE Transactions on Reliability 64 (3), pp. 861–868, DOI: 10.1109/TR.2015.2424213.

uses, such as the automated detection of inefficient loading[25], or the prediction of estimated times of arrival of freight trains[26]. Further possibilities for AI arise in optimizing the timing and safety of passenger trains, for example with the deployment of autonomous trains and urban trams using AI technology.

Buildings and Cities

Building Heating and Cooling

Indoor climate control is the main source of energy consumption in buildings. AI-based prediction and control can lead to substantial energy efficiency gains in heating, ventilation, and air conditioning (HVAC) systems for residential, commercial, and industrial applications[27], and it can provide new flexible demand options for balancing the power grid[28]. AI can be used to improve operations by predicting heating demand, optimizing different fuel and energy storage options, and detecting failures and losses in HVAC systems. Commercial and industrial buildings are particularly suitable for AI-assisted HVAC operations, which often come with additional requirements regarding maintaining storage and production conditions, and inventory such as stationary processing machines and compute servers. District heating and cooling systems provide a near term option to leverage AI-based technologies for residential HVAC, since those are operated centrally. Studies have shown that AI can help with increasing operational efficiency and integrating renewable energy

[25] Lai, Y. C., Barkan, C. P. L., Drapa, J., Ahuja, N., Hart, J. M., Narayanan, P. J., Jawahar, C. V., Kumar, A., Milhon, L. R., Stehly, M. P., 2007. Machine vision analysis of the energy efficiency of intermodal freight trains. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 221 (3), pp. 353–364.

[26] Barbour, W., Mori, J. C. M., Kuppa, S. and Work, D. B., 2018. Prediction of arrival times of freight traffic on US railroads using support vector regression. Transportation Research Part C: Emerging Technologies 93, pp. 211–227.

[27] Kazmi, H., Mehmood, F., Lodeweyckx, S. and Driesen, J., 2018. Gigawatt-hour scale savings on a budget of zero: Deep reinforcement learning based optimal control of hot water systems. Energy, 144, pp.159–168.

[28] Hu, Q. and Li, F., 2013. Hardware design of smart home energy management system with dynamic price response. IEEE Transactions on Smart grid, 4 (4), pp.1878–1887.

sources in district energy systems.[29] About 20 percent of Austrian apartments are served with district heating systems.

Urban Planning

AI is increasingly used for sustainability applications in urban areas.[30] For example, AI can be used to improve computationally intensive simulations of wind flow around buildings, which are needed to understand local air pollution concentration, natural ventilation, and pedestrian comfort[31]. Computing such models is very time-intensive, which makes it difficult to use them in planning processes. AI-based surrogate models are trained on many runs of the original simulation model, which allows the system to learn how to approximately provide the right output for every input configuration. The AI-enabled version can produce predictions of wind flow around all buildings in a city with nearly the same accuracy but much faster, reducing computational time by several orders of magnitude. This allows city planners to try out the effects of different building arrangements on wind flow in urban areas, and ultimately design more walkable, healthy, and sustainable cities. Similar approaches are for example also used for analyzing the energy consumption in urban building stocks.[32]

Remote Sensing with AI

AI has led to enormous improvements in remote sensing, for example by way of new object detection and segmentation methods. In combination with the increasing availability of satellite imagery, there is a wide range of new possibilities for remote sensing to monitor the environment and to provide better decision-making

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[29] Reynolds, J., Ahmad, M. W., Rezgui, Y. and Hippolyte, J. L., 2019. Operational supply and demand optimisation of a multi-vector district energy system using artificial neural networks and a genetic algorithm. Applied energy, 235, pp. 699–713.

[30] Rolnick, D., Donti, P. L., Kaack, L. H., Kochanski, K., et al., 2019. Tackling climate change with machine learning. https://arxiv.org/abs/1906.05433.

[31] Intelligent Framework for Resilient Design; cf. http://infrared.city

[32] Vazquez-Canteli, J., Dilsiz Demir, A., Brown, J., Nagy, Z., 2019. Deep neural networks as surrogate models for urban energy simulations. Journal of Physics: Conference Series 1343, DOI: 10.1088/1742-6596/1343/1/012002.

support.[33] For example, the European Copernicus Project[34] is a large effort to make such information usable for authorities and various stakeholders, including supporting disaster response and providing information to farmers. Other approaches have, for example, used AI-based remote sensing for detecting logging activities in tropical forests[35], monitoring road freight traffic[36], mapping the built infrastructure[37], and various other applications.

On-Site Sensing with AI

Embedding sensor nodes with efficient onboard AI-algorithms in the environment is an emerging blueprint for various future "edge-based" distributed data processing applications that can produce local analyses and decisions without the need for large data centers. Application scenarios include, e.g., mountainous regions and natural gas pipelines.

Mountainous regions, which make up large parts of Austria, are heavily impacted by climate change (e.g., by rising temperatures leading to the retraction of glaciers and permafrost degradation)[38]. This does not only dramatically change mountain ecosystems and impact local economies, but it also affects rock stability. Wireless sensor networks can be deployed in neuralgic areas in order to measure seismic anom-

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[33] Zhu, X. X., Tuia, D., Mou, L., Xia, G.-S., Zhang, L., Xu, F., Fraundorfer, F., 2017, December. Deep Learning in Remote Sensing: A Comprehensive Review and List of Resources, IEEE Geoscience and Remote Sensing Magazine 5 (4), pp. 8–36, DOI: 10.1109/MGRS.2017.2762307

[34] Copernicus; cf. https://www.copernicus.eu/en

[35] Hethcoat, M. G., Edwards, D. P., Carreiras, J. M., Bryant, R. G., Franca, F. M., Quegan, S., 2019. A machine learning approach to map tropical selective logging. Remote sensing of environment, 221, pp. 569–582.

[36] Kaack, L. H., Chen, G. H. and Morgan, M. G., 2019, July. Truck traffic monitoring with satellite images. Proceedings of the 2nd ACM SIGCAS Conference on Computing and Sustainable Societies, pp. 155–164.

[37] Microsoft. Computer generated building footprints for the United States. https://github.com/Microsoft/USBuildingFootprints.

[38] Hock, R., Rasul, G., et al., 2019. High Mountain Areas. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.

alies that indicate problematic events such as rockfall, flooding, or landslide. Efficient data processing can be realized by running AI-based signal detectors on embedded edge devices, thus reducing the need for energy-heavy medium or long-range data transmission.[39]

Methane, the primary constituent of natural gas, is a potent greenhouse gas. AI and robotics can be used to help detect leaks from natural gas infrastructure (e.g., pipelines and compressor stations). Austria is a natural gas hub and could benefit from such technologies, which have the potential to drive down costs and reduce fugitive emissions from natural gas facilities[40,41]. By employing on-site sensing techniques, sites can be scanned for leaking natural gas (e.g., through drones equipped with methane sensors or pipe crawling robots)[42]. It has been shown that computer vision with AI can help to automatically assess imagery collected with infrared cameras for methane plumes[43], which opens up possibilities for new automated detection technologies extending much further than only natural gas leak detection.

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39 Meyer, M., et al., 2019. Event-triggered Natural Hazard Monitoring with Convolutional Neural Networks on the Edge. Proceedings of the 18th International Conference on Information Processing in Sensor Networks, pp. 73–84. DOI: 10.1145/3302506.3310390.

40 Mayfield, E. N., Robinson, A. L. and Cohon, J. L., 2017. System-wide and superemitter policy options for the abatement of methane emissions from the US natural gas system. Environmental science & technology, 51 (9), pp. 4772–4780. DOI : 10.1021/acs.est.6b05052.

41 Wang, J., Ravikumar, A. P., and Brandt, A. R. 2019. Techno-economic Analysis of Deep-Learning-Enabled Automated Natural Gas Leakage Detection Technologies. AGUFM 2019, GC51M-0960.

42 Ravikumar, A. P., Sreedhara, S., Wang, J., Englander, J., Roda-Stuart, D., Bell, C., Zimmerle, D., Lyon, D., Mogstad, I., Ratner, B. and Brandt, A. R., 2019. Single-blind inter-comparison of methane detection technologies – results from the Stanford/EDF Mobile Monitoring Challenge. Elem Sci Anth, 7 (1), DOI: 10.1525/elementa.373.

43 Wang, J., Tchapmi, L. P., Ravikumar, A. P., McGuire, M., Bell, C. S., Zimmerle, D., Savarese, S., Brandt, A. R., 2020. Machine vision for natural gas methane emissions detection using an infrared camera. Applied Energy, 257.

Environmental Protection

While methods for addressing climate change often also result in environmental protection, it is worth mentioning AI technologies that can explicitly contribute to environmental protection without necessarily addressing climate change.

Circular Economy

Circular economy aims at reducing resource demand by keeping products and materials in use. Currently, the reuse of products or components is not economically viable for many products, mostly because these components are manufactured in a way that makes resource reuse laborious and thus expensive[44]. By making products that can be disassembled using automation technology, resource reuse becomes economically feasible. This automation technology can be powered by robotics and AI and enable cost-efficient sorting and disassembly.[45] In general, AI holds great promise to contribute to many aspects of a circular economy.[46]

Increased use of circular economy approaches also holds immense potential in the area of energy production both for conventional energy technologies and alternative energy sources. The increased use of renewable energy technologies is only the first step. Currently, there are still significant waste management deficits for the materials such as photovoltaic panels, wind turbines or storage batteries. It is necessary to employ end-of-life strategies to enable the reuse of even complex or environmentally harmful material types, beyond the combustibles used[47].

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[44] Poschmann, H., Bruggemann, H., Goldmann, D., 2020, March. Disassembly 4.0: A Review on Using Robotics in Disassembly Tasks as a Way of Automation. Chemie Ingenieur Technik 92 (4), pp. 341–359, DOI: 10.1002/cite.201900107.

[45] Wegener, K., Chen, W. H., Dietrich, F., Dröder, K., Karab, S., 2015. Robot Assisted Disassembly for the Recycling of Electric Vehicle Batteries, Procedia CIRP 29, pp. 716–721, DOI: 10.1016/j.procir.2015.02.051.

[46] cf. the various opportunities for employing AI to promote a circular economy in: Ellen MacArthur Foundation, 2019. Artificial intelligence and the circular economy – AI as a tool to accelerate the transition. https://www.ellenmacarthurfoundation.org/publications/artificial-intelligence-and-the-circular-economy

[47] Mulvaneya, D., Richards, R. M., Bazilian, M. D., Hensley, E., Clough, G., Sridhar, S., 2021. Progress towards a circular economy in materials to decarbonize

Circular economy approaches can be enforced by an increased standardization for cyclical transportation flows. In some cases, this has been done since long (e.g., ISO-standardized containers). However, there is still need for improvement regarding product (re-)packaging, container/vessel interior, labeling, tracking, and tracing, hard- and software interfaces, transport legislation, and other applications. AI algorithms could be utilized to coordinate both the delivery and return of items more efficiently and in a more environmentally friendly way.

The agricultural sector also offers numerous potentials for circular processes, for example, with smart technologies for water reuse, organic waste utilization, recycling of raw materials up to intelligent container, reservoir, vessel, and silo management (e.g., for crop products, feed materials, liquids, and other reusable resources). Empirical case studies[48,49] suggest, however, that in many agricultural value chains, the basic requirements for the application of AI need to be established first, especially regarding connectivity, digital process chain design and the basic knowledge for the use of AI technologies.

electricity and mobility, Renewable and Sustainable Energy Reviews 137, in press, DOI: 10.1016/j.rser.2020.110604.

48 Abdul-Hamid, A.-Q., Ali, M. H., Tseng, M.-L., Lan, S., Kumar, M., 2020. Impeding challenges on industry 4.0 in circular economy: Palm oil industry in Malaysia. Computers & Operations Research 123, DOI: 10.1016/j.cor.2020.105052.

49 Stahl, B. C., Andreou, A., Brey, P., Hatzakis, T., Kirichenko, A., Macnish, K., Laulhé Shaelou, S., Patel, A., Ryan, M., Wright, D., 2020. Artificial intelligence for human flourishing – Beyond principles for machine learning. Journal of Business Research 124, pp. 374–388, DOI: 10.1016/j.jbusres.2020.11.030

The broad application of AI technologies and the required decoupling of supply network value creation from the consumption of non-recovered primary resources, still require considerable effort[50,51,52].

Environmental Cleanup

Robots can perform a variety of autonomous cleaning tasks in urban, suburban, and rural environments (e.g., collecting and removing garbage on roads and from sewers and rivers, removing plastics from oceans)[53]. The collected waste can later be automatically inspected and sorted for recycling.

Pollution Monitoring

Stationary and mobile sensor networks can be used to measure different types of pollution (e.g., air quality measurements at different urban locations, pollution under water, in the air, etc.). Furthermore, imaging techniques enable a human-understandable visual representation of pollutant emissions using satellite-based surveying. AI-based analysis tools can then be used to quantify the image data which is available in a structured form ready to be used by authorities for taking action towards mitigation (e.g., the investigation of operations in which increased pollutant emissions were indicated).

[50] de Jesus, A., Mendonça, S., 2018. Lost in Transition? Drivers and Barriers in the Eco-innovation Road to the Circular Economy. Ecological Economics 145, pp. 75–89, DOI: 10.1016/j.ecolecon.2017.08.001.

[51] Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., Hekkert, M., 2018. Barriers to the Circular Economy: Evidence From the European Union (EU), Ecological Economics 150, pp. 264–272, DOI: 10.1016/j.ecolecon.2018.04.028.

[52] Pieroni, M. P. P., McAloone, T. C., Borgianni, Y., Maccioni, L., Pigosso, D. C. A., 2021. An expert system for circular economy business modelling: advising manufacturing companies in decoupling value creation from resource consumption, Sustainable Production and Consumption, in press, DOI: 10.1016/j.spc.2021.01.023.

[53] cf. https://theoceancleanup.com/

Protection of Species

The protection of so-called "beneficial insects" is an important aspect of protecting ecosystems while also increasing robustness to climate change. Especially pollinators (such as bees) play an essential role, but they are endangered by different influences (e.g., the increased use of pesticides and herbicides in agriculture, but also pests and other diseases). With the help of sensors (temperature, humidity, microphones, etc.) and imaging techniques, AI systems can help to better understand the behavior of insect species, for example, and subsequently provide assistance in keeping the corresponding populations healthy[54].

Robots can be used to protect natural landscapes and endangered species (e.g., by planting native species, supporting pollinators and targeted control of invasive species by weeding, mowing, fertilizing, but also the explicit removal of invasive species).

Policy Analysis

Policy analysis is concerned with providing information for decision makers and analyzing the effectiveness of policy approaches. Many assessments in policy analysis are difficult and uncertain because the data are either not available or appear in a form that makes them burdensome to analyze. AI can offer new opportunities for extracting decision-relevant information from these data. Above we have described such approaches, for example mapping infrastructure with remote sensing based on satellite images. Another large source of information on climate policy comes in form of text data. These texts typically need to be analyzed manually, but computerized techniques and new AI-based approaches have emerged for automated analysis of texts. Such an analysis can, for example, help with compiling IPCC reports[55],

[54] cf. https://www.beewise.ag/

[55] Minx, J. C., Callaghan, M., Lamb, W. F., Garard, J., and Edenhofer, O. 2017. Learning about climate change solutions in the IPCC and beyond. Environmental Science & Policy, 77, pp. 252–259.

with understanding ideological polarization[56], and with analyzing corporate financial disclosures of climate-related risks[57].

Discussion

The previous sections pointed to the potential that current and future AI technologies have for mitigating the effects of climate change and for protecting the environment. AI technologies, however, can also be applied in ways that are detrimental to the climate and environment, for example for oil and gas exploration[58]. In addition, new AI-driven technologies often have complex effects on energy systems that in certain cases can negate and even exceed GHG emission reductions, for example in form of rebound effects that can reduce efficiency gains. Another example is the case of autonomous vehicles, where there are a number of different effects that could either increase or decrease energy consumption, leaving it uncertain whether AVs will have a net positive or negative impact on the climate.[59] When evaluating climate impact, the power consumed by the compute servers running AI algorithms also needs to be taken into account. Certain AI technologies, like very deep neural networks, have high energy demands, while other AI technologies can run on a laptop.[60]

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[56] Farrell, J. 2016. Corporate funding and ideological polarization about climate change. PNAS; Proceedings of the National Academy of Sciences, 113 (1), pp. 92–97.

[57] Kölbel, J. F., Leippold, M., Rillaerts, J., and Wang, Q. 2020. Does the CDS market reflect regulatory climate risk disclosures? Available at SSRN.

[58] Greenpeace, 2020. Oil in the Cloud: How Tech Companies are Helping Big Oil Profit from Climate Destruction. Available at: https://www.greenpeace.org/usa/reports/oil-in-the-cloud

[59] For a discussion of the multi-faceted relationship of AI and climate change, see Wadud, Z., MacKenzie, D., Leiby, P., 2016, April. Help or hindrance? the travel, energy and carbon impacts of highly automated vehicles. Transportation Research Part A: Policy and Practice, 86, pp. 1–18, ISSN: 0965-8564, DOI: 10.1016/j.tra.2015.12.001.

[60] Kaack, L. H., Donti, P. L., Strubell, E., Rolnick, D., 2020. Artificial Intelligence and Climate Change. Opportunities, considerations, and policy levers to align AI with climate change goals, Heinrich Böll Stiftung.

As with all technologies, the choice of which AI technologies to deploy and for what purpose have to be carefully weighed against alternatives and considered in the broader societal context both in Austria and in the EU. For example, upholding ethical principles of human dignity, fairness, equality, transparency, safety, privacy, and others must be an essential requirement for any AI application, small or large. Hence, we believe that in addition to the brief survey of AI applications for addressing climate change and environmental protection, it would be useful to step back and provide a set of considerations in need of reflection as policy frameworks for utilizing AI technology are taking shape.

Impact Assessment

Many AI and robotics applications to address climate change and protect the environment are relatively new, including the approaches laid out in this paper. As a result, there are currently few quantitative estimates of GHG emission reduction and potential for environmental protection of these technologies, with most estimates being limited to certain sub-fields and case studies. Given the ambitious decarbonization timeline, however, it is important to evaluate the potential effects of technologies and prioritize between different options, both for individual organizations and policy makers. For organizations looking to leverage AI options, case studies of similar projects can nonetheless provide some guidance. As new technologies, such as AI, can carry additional burdens and risks, organizations also need to question on a case-by-case basis if simpler alternatives to AI exist that can achieve the same impact, if the proposed AI approach is feasible given factors like data availability, costs, and organizational capacity, and if risks and (unintended) consequences are well-understood and manageable. Such considerations also play a role when designing policies to promote AI for climate change mitigation and environmental protection. Policy-makers need to ensure that AI approaches can be adopted fast and at scale, that risks to society are manageable, and that they are not in conflict with other decarbonization approaches. For example, AI and data requirements should not constitute significant hurdles to low-carbon technologies.

Ethical Considerations

There are a number of well-known ethical issues raised by artificial intelligence, as pointed out in various sources[61,62]. For the responsible development of AI in Austria, it is necessary that these technologies are developed in a way that takes into account issues such as privacy and data protection, security, transparency, mitigation of bias, human agency, and employment effects. All these properties need to be regarded by corresponding legal frameworks and/or regulations in order to make them mandatory and binding – for all players in this field.

Using AI to steer the behavior of people and shape society (social engineering), for example via "nudging", in order to increase recycling and energy-saving behavior, may be problematic in terms of the freedom and dignity of human beings and citizens' rights, unless there is consensual agreement on the purpose and the use of the specific AI application. If such methods are deemed ethically problematic, other methods need to be considered, such as argumentation and raising awareness.

Labor Market Considerations

The application and use of AI technologies directly impacts the labor market, which is also relevant for environmental and climate applications. Hence, it is vital to mitigate any expected negative effects through effective measures and proactive investments. Among these are making resources for training and education available on an individual, enterprise, and industry level. It is especially important to include means of training and continued education on the job, as the digital transformation of jobs has different implications in different business sectors, not the least because the transformation of jobs will hit people who are in the middle or at the end of their career especially hard. This includes guidance on how to transition from

61 Coeckelbergh, M., 2020, April. AI Ethics. The MIT Press Essential Knowledge series. ISBN: 9780262538190

62 High-Level Expert Group on Artificial Intelligence, 2019, April. Ethics Guidelines for Trustworthy AI.

jobs likely to be performed by AI (e.g., sorting trash and recyclables, mowing public lands, etc.) to new jobs with better job conditions[63].

While advances in AI will clearly bring new job opportunities, they also risk widening disparities among workers[64], a potential danger that needs to be addressed in any regulatory framework.

Legal Considerations

In its White Paper on AI[65], the European Commission proposes that: "[…] the new regulatory framework for AI should be effective to achieve its objectives while not being excessively prescriptive so that it could create a disproportionate burden, especially for SMEs [small and medium-sized enterprises]. To strike this balance, the Commission is of the view that it should follow a risk-based approach."[66] The Commission further specifies that "[…] a given AI application should generally be considered high-risk in light of what is at stake, considering whether both the sector and the intended use involve significant risks, in particular from the viewpoint of protection of safety, consumer rights and fundamental rights."[67] With respect to the mitigation of climate change and the protection of the environment, even more factors (in addition to, e.g., fundamental human rights violations as well as inconsistencies with fundamental ethical values) need to be considered before a holistic evaluation of the impact of AI applications can be reached. To date, the governance mecha-

63 While there are 9 to 12 percent of currents jobs at risk of automation, the overall net difference between jobs created and jobs lost due to technological advances are estimated to be positive. According to a WIFO study, increased efforts and investments in digitalizing Austria's economy can lead to an increase of employment by up to 0.4 percent annually, cf. Peneder, M., Bock-Schappelwein, J., Firgo, M., Fritz, O., Streicher, G., 2017. Ökonomische Effekte der Digitalisierung in Österreich. WIFO-Monatsberichte, 90 (3), pp. 177–192.

64 OECD Employment Outlook 2019, The Future of Work, OECD Publishing, DOI: 10.1787/9ee00155-en.

65 European Commission, 2020, February. White Paper on Artificial Intelligence – A European approach to excellence and trust. COM(2020) 65 final.

66 ibid.

67 ibid. Accentuation adopted from original.

nisms for such assessment processes have not been decided and there is an ongoing discussion whether risk-based approaches are appropriate. While certification authorities could be part of a possible solution, it is, regardless, essential that clear evaluation criteria be defined for an initial regulatory and legal framework to allow technology providers to set up their development and deployment processes accordingly.

Clearly, this cannot just be a national effort, but needs to take place on the international stage, at least at the European level.[68]

[68] For a European discussion, cf. High-Level Expert Group on Artificial Intelligence, 2019, June. Policy and Investment recommendations for Trustworthy AI.

Conclusion

AI technology has the potential for combating climate change and protecting our environment, but whether and to what extent AI can make a contribution will depend on both the AI technologies and how they are deployed. To be able to maximize the benefits for societies in general, and Austria in particular, a regulatory framework needs to be put in place that both carefully considers the application domains for employing AI technology as well as the societal effects of doing so, both locally and globally. We believe that, if done right, AI technology can help us address the most existential threats of our time without sacrificing human values, or rattling societies in ways that could, instead of improving, destabilize them (e.g., due to inequality, access limitations, lack of privacy, etc.). Therefore, to ensure that AI is used to address climate change and protect the environment, any national AI strategy needs to promote interdisciplinary, multi-perspective research and collaboration of AI researchers and roboticists with scientists working on climate change from across a number of different disciplines. We believe that Austria has a unique opportunity for leadership by proposing a framework based on this document that could resonate with partners at the European level and thus garner the support its needs to be widely adopted.

The Members of the Council