



Application Aware, Life-Cycle Oriented Model-Hardware Co-Design Framework for Sustainable, Energy Efficient ML Systems

Annual report on collabora- tion - Y2

Deliverable D7.8

WP7 - Dissemination, Exploitation and
Management



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Co-Design Framework for Sustainable, Energy Efficient ML Systems

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v2.0	23/09/2024	UPMEM	Yann Falevoz	UPMEM collaborations
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Executive summary

SustainML project aims to develop a design framework and an associated toolkit, so-called SustainML, that will foster energy efficiency throughout the whole life-cycle of Machine Learning (ML) applications: from the design and exploration phase that includes exploratory iterations of training, testing and optimizing different system versions through the final training of the production systems (which often involves huge amounts of data, computation and epochs) and (where appropriate) continuous online re-training during deployment for the inference process. The framework will optimize the ML solutions based on the application tasks, across levels from hardware to model architecture. It will also collect both previously scattered efficiency-oriented research, as well as novel Green-AI methods. Artificial Intelligence (AI) developers from all experience levels can make use of the framework through its emphasis on human-centric interactive transparent design and functional knowledge cores, instead of the common blackbox and fully automated optimization approaches.

This report corresponds to *Deliverable D7.8 - Annual report on collaboration - Y2* of the SustainML project. This deliverable covers the main collaborations between SustainML consortium members and research groups, organizations, EU projects and communities external to the project.

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Acronyms

AI	Artificial Intelligence.
ML	Machine Learning.
ROS	Robot Operating System.
TSC	Technical Steering Committee.

1 Collaboration with other EU projects and initiatives

1.1 Humane-AI-Net

Humane-AI-Net (Grant agreement 952026) ¹ is an EU-funded ICT48 network of AI excellence centers with over 50 partners including AI research institutes, national incubators, industry application partners, etc. across Europe. DFKI is the coordinator of Humane-AI-Net and has promoted the SustainML project in the recent networking events, including a consortium meeting in Krakow, Poland which took place together with the European Conference on AI (2023).

1.2 ALMA

Algebraic Machine Learning (AML) is a relatively new machine learning technique based on algebraic representations of data. Unlike statistical learning, AML algorithms are robust regarding the statistical properties of the data and are parameter-free. The aim of the EU-funded ALMA² project is to leverage AML properties to develop a new generation of interactive, human-centric machine learning systems. These systems are expected to reduce bias and prevent discrimination, remember what they know when they are taught something new, facilitate trust and reliability and integrate complex ethical constraints into human-artificial intelligence systems. Furthermore, they are expected to promote distributed, collaborative learning.

Some partners of SustainML project are also members of ALMA consortium (DFKI, eProxima, RPTU, and Inria). This will facilitate the integration and use of the results obtained from the ALMA project in the SustainML project tasks, making it possible to test the resulting framework with AML models.

1.3 Pro2Future Symposium

Within the Pro2Future Symposium on Sustainable and Cognitive Products and Production held in Linz, Austria on 22.06.23, Paul Lukowicz gave a keynote speech entitled "Why smaller is better: Edge Embedded AI for Smart Production".

1.4 Carl-Zeiss foundation SembAI

Sustainable Embedded AI (SEmbAI)³ is a multi-year research project funded by the Carl-Zeiss Foundation in Germany. The project focuses on novel embedded AI applications with data and energy efficiency and has shared principle as SustainML. DFKI and RPTU are both participants in SEmBAI and has started to investigate collaboration opportunities in sustainable embedded AI.

1.5 TALON

TALON⁴ introduces an AI orchestrator that envisions transforming the I5.0 into an automated intelligent platform by exploiting advances in edge networks and bringing intelligence near sensors in embedded systems with limited computational, storage, and communication resources, as well as the integration of advanced and adaptive sensors and perception.

¹<https://www.humane-ai.eu>

²<https://alma-ai.eu/>

³<https://sembai.cs.uni-kl.de>

⁴<https://talon-project.eu/>

In this direction, TALON's AI orchestrator maximizes both global and individual users' and systems' capabilities without violating the design parameters of each application. In particular, the orchestrator selects AI datasets, algorithms, metrics, and models based on the application.

eProxima has participated in the *Establishing the next level of "intelligence" and autonomy Clustering Workshop Event*⁵ organised by the EU-funded project TALON in close collaboration with the projects AutoFair⁶, ENEXA⁷, EVENFLOW⁸, REXASI-PRO⁹, SAFEXPLAIN¹⁰, SustainML¹¹, TUPLES¹², and ULTIMATE¹³ funded under the HORIZON-CL4-2021-HUMAN-01-01 topic. This workshop aims at bringing together projects and experts for exploring synergies and identifying actions that can be pursued in common in the area of verifiable robustness, energy efficiency and transparency for trustworthy AI. Future collaboration between different European projects was one of the key topics discussed.

1.6 BioPIM

In addition to spearheading the groundbreaking developments within the framework of the EIC Accelerator, UPMEM is proud to be an active participant in several collaborative projects, fostering innovation both at the national and European scales. Our engagement spans five prominent European projects (including SustainML) and two national initiatives, forming a rich tapestry of collaborative efforts. These diverse projects not only underline UPMEM's commitment to cross-disciplinary collaboration but also hold the promise of mutually reinforcing successes. The synergy between these endeavors presents a unique opportunity for knowledge exchange, technological advancements, and the acceleration of sustainable solutions.

UPMEM is one of the consortium partners of BioPIM¹⁴ (Grant agreement ID: 101047160). This project is dedicated to harnessing processing-in-memory (PIM) technologies for enhanced edge computing in bioinformatics. By co-designing algorithms and data structures with various PIM architectures, BioPIM aims to achieve optimal cost-effectiveness, energy efficiency, and time savings in bioinformatics applications. This project aligns seamlessly with the objectives of SustainML. The advancements in PIM technologies explored in SustainML, particularly in Task 2.3 focusing on energy-efficient hardware for machine learning, can significantly benefit BioPIM. The cross-disciplinary insights and innovations developed in SustainML provide valuable foundations for BioPIM, ensuring a symbiotic relationship where the sustainable machine learning practices pioneered by SustainML contribute to the efficiency and success of BioPIM's endeavors in bioinformatics and beyond.

⁵<https://talon-project.eu/eventsestablishing-the-next-level-of-intelligence-and-autonomy-clustering-workshopevents/>

⁶<https://humancompatible.org/>

⁷<https://enexa.eu/>

⁸<https://evenflow-project.eu/>

⁹<https://rexasi-pro.spindoxlabs.com/>

¹⁰<https://safexplain.eu/>

¹¹<https://sustainml.eu/>

¹²<https://tuples.ai/project/>

¹³<https://ultimate-project.eu/>

¹⁴<http://biopim.eu>

1.7 STRATUM

STRATUM (responding to the HORIZON-HLTH-2023-TOOL-05-05 call, GA under preparation, and with UPMEM as part of the project consortium) focuses on developing a 3D Decision Support Tool for brain surgery guidance and diagnostics, integrating AI algorithms and energy-efficient computing solutions. As SustainML advances machine learning practices for sustainability, the methodologies and innovations fostered by the project could significantly benefit STRATUM. The cross-disciplinary insights and energy-efficient computing techniques developed in SustainML offer valuable foundations for STRATUM's mission to improve intraoperative diagnostic accuracy and reduce surgery time in brain tumor surgeries.

1.8 TIRESYAS

TIRESYAS (responding to the EDF-2022-RA-SENS-ART call, GA under preparation, and with UPMEM as part of the project consortium) focuses on enhancing radar capabilities to counter emerging threats. The project aims to bolster sensor resilience, sustainability, and operational efficiency. As TIRESYAS explores intensive computation, signal processing, and cyber resilience, SustainML may offer valuable perspectives on optimizing energy efficiency and sustainable practices within the radar technology domain, contributing to the overarching goal of enhancing radar performance while ensuring environmental sustainability.

1.9 ARCHYTAS

The ARCHYTAS project (responding to the EDF-2023-RA-DIGIT-HAAI call, Dedicated hardware architectures for energy-efficient AI, GA under preparation, and with UPMEM as part of the project consortium) aims to investigate unconventional AI accelerators that take advantage of novel technologies: optoelectronic-based accelerators, volatile and non-volatile processing-in-memory, and neuromorphic devices. ARCHYTAS also explores the integration of CMOS-based systems with analogue accelerators, as well as new programming models to improve the programmability, performance portability, and productivity of these emerging parallel systems through a hardware-AI co-design approach. The accelerators developed by the ARCHYTAS project could significantly enrich the hardware recommendations generated by the SustainML framework. By incorporating these energy-efficient technologies, SustainML could further reduce the energy consumption and CO_2 emissions of AI applications throughout their training and exploitation phases.

2 Trustworthy AI Cluster

Nine projects funded under the Horizon Europe call, HORIZON-CL4-2021-HUMAN-01-01, will help pave the way for the greater acceptance of Artificial Intelligence (AI) across Europe. These projects share a common goal of shaping AI solutions that are innovative, human-centric and dependable. Among others, the main focus is on verifiable robustness, energy efficiency and transparency.

Each of these projects brings a unique perspective to the broad realm of trustworthy AI. Driven by the collective aim of fostering trust and confidence in AI technology, these initiatives are geared towards enhancing transparency, explainability, accountability, safety and performance in systems using AI.

The collaborative spirit of these projects is clear as the projects embark on shared efforts to understand each other's objectives and identify opportunities for synergies. These "cluster" activities work to ensure a cohesive strategy that aligns with the overall call objectives and the Digital Europe Strategy.

The following nine projects are part of the call and each project provides solid scientific solutions complemented by tools and processes for design, testing, validation, certification, software engineering method-



Figure 1: Trustworthy AI Cluster Banner

ologies and real-world applications.

- AutoFair¹⁵: Human-Compatible Artificial Intelligence with Guarantees.
- ENEXA¹⁶: Efficient Explainable Learning on Knowledge Graphs.
- EVENFLOW¹⁷: Robust Learning and Reasoning for Complex Event Forecasting.
- REXASI-PRO¹⁸: REliable and eXplAinable Swarm Intelligence for People with Reduced mObility.
- SAFEXPLAIN¹⁹: Safe and Explainable Critical Embedded Systems Based on AI.
- SustainML²⁰: Application-Aware, Life-Cycle Oriented Model-Hardware Co-Design Framework for Sustainable, Energy Efficient ML Systems.
- TALON²¹: Autonomous and self-organized artificial intelligent orchestrator for a greener industry 4.0.
- TUPLES²²: Trustworthy Planning and Scheduling with Learning and Explanations

¹⁵AutoFair: <https://www.aic.fel.cvut.cz/projects/autofair>

¹⁶ENEXA: <https://enexa.eu/>

¹⁷EVENFLOW: <https://evenflow-project.eu/>

¹⁸REXASI-PRO: <https://rexasi-pro.spindoxlabs.com/>

¹⁹SAFEXPLAIN: <https://safexplain.eu/>

²⁰SustainML: <https://sustainml.eu/>

²¹TALON: <https://talon-project.eu>

²²TUPLES: <https://tuples.ai/>

- ULTIMATE²³: mUlti-Level Trustworthiness to IMprove the Adoption of hybrid arTificial intelligence.

By pooling their collective expertise, visions and communication channels, these projects aim to amplify their impact mutually.

The European AI strategy seeks to position the EU as a world-class hub for AI. This is why collaboration and synergies are a driving force of the European research landscape and a key player in the strategy. The core goal is to address the challenges of AI trust and uptake, ensuring that AI solutions are not only cutting-edge but also resonate with European values.

For more information about this collaboration and the projects funded under HORIZON-CL4-2021-HUMAN-01-01, visit <https://cordis.europa.eu/search?q=contenttype%3D%27project%27%20AND%20programme%2Fcode%3D%27HORIZON-CL4-2021-HUMAN-01-01%27&p=1&num=10&srt=/project/contentUpdateDate:decreasing>.

2.1 Joint communication and dissemination plan

The nine Horizon Europe projects focused on Trustworthy AI have established a comprehensive joint communication and dissemination plan to maximize the visibility and impact of their collective work. These projects—AutoFair, ENEXA, EVENFLOW, REXASI-PRO, SAFEXPLAIN, SustainML, TALON, TUPLES, and ULTIMATE—are all funded under the Horizon Europe call HORIZON-CL4-2021-HUMAN-01-01, with the shared goal of fostering trustworthy and human-centric artificial intelligence (AI) solutions across Europe. Given the complexity of AI challenges and the need to build public trust in this technology, these projects have recognized the importance of working together, not only in terms of scientific collaboration but also in communication and outreach efforts.

A key element of the joint strategy is cross-referencing and promoting each project's activities on social media and other digital platforms. By using their communication channels to promote the cluster and reference the sibling projects of the cluster, the projects can create a unified presence that highlights the individual contributions of each initiative while demonstrating their shared commitment to advancing trustworthy AI. This coordinated approach ensures that stakeholders, including researchers, industry partners, policymakers, and the general public, are continuously informed about the latest developments, breakthroughs, and events related to the projects. Through regular updates, scheduled for every month, targeted campaigns, and coordinated messaging, the projects aim to increase engagement and interaction with diverse audiences.

In addition to social media efforts, the dissemination plan involves organizing and participating in various events, such as conferences, workshops, and webinars, to share their research findings and technological innovations. These events serve as platforms to showcase the projects' progress, foster dialogue with key stakeholders, and explore opportunities for collaboration within the AI community and beyond. The events will also focus on addressing the broader societal implications of AI, such as transparency, explainability, and ethical considerations, aligning with the European AI strategy's emphasis on human-centric and responsible AI development.

²³ULTIMATE: <https://ultimate-project.eu/>

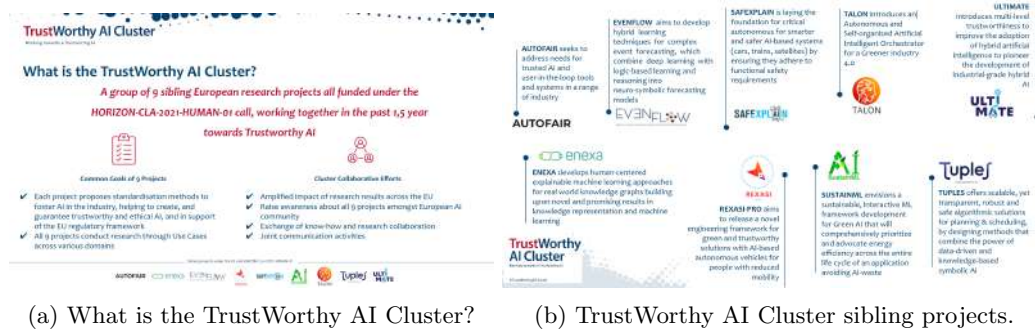


Figure 2: Joint communication of TrustWorthy AI Cluster.

By pooling their expertise and resources, the collaboration between projects makes it possible to host large-scale events that attract a wide range of participants, including industry leaders, academic researchers, policymakers, and civil society organizations. This approach not only helps to amplify the projects' impact but also strengthens their connections with various sectors, promoting a deeper understanding of trustworthy AI and its potential benefits for society. In doing so, the projects contribute to the European Union's goal of positioning itself as a global leader in AI research and innovation.

Another significant aspect of the joint dissemination plan is the focus on creating synergies between the projects. The projects will regularly share insights, research outcomes, and best practices, fostering a collaborative environment that encourages knowledge exchange and interdisciplinary collaboration. By doing so, the projects aim to avoid duplication of efforts and ensure that their findings and innovations complement and reinforce each other.

Overall, the joint communication and dissemination strategy reflects the collaborative efforts of these nine Horizon Europe projects. By working together to raise awareness, share knowledge, and engage with stakeholders, the projects aim to drive forward the adoption of trustworthy AI technologies that are aligned with European values. Through these efforts, they contribute not only to the scientific and technological advancement of AI but also to fostering public trust and confidence in AI systems across Europe.

2.1.1 Participation in events, webinars and workshops

Webinar Trustworthy AI: Landscaping verifiable robustness & transparency

SustainML along with its sibling projects of the TrustWorthy AI Cluster and Adra-e — AI, Data and Robotics Ecosystem co-organised the webinar titled Trustworthy AI: Landscaping verifiable robustness and transparency on 29 May 2024.

The webinar aimed to show the progress in the development of Trustworthy AI technology and introduce verifiable robustness and transparency in the Artificial Intelligence domain, while it was addressed professionals, researchers, and stakeholders interested in AI, Data, and Robotics, but also welcomed participants from academia, industry, and government sectors seeking insights into Research and Innovation Actions (RIAs) projects.

Evangelia Markidou, from the European Commission, welcomed the participants, while the three flagship projects ADRA-e, AI4Europe and DeployAI elaborated on how is trustworthy AI manifested in these flagship projects. Elena Galifianaki, Head of Communication of EVENFLOW, followed with an introduction of the TrustWorthy AI Cluster.

The video recording and all the slides presented have publicly available in the Adra-e website ²⁴.



(a) Banner of Trustworthy AI Webinar at Adra-e



(b) "TrustWorthy AI in SustainML" by Raúl Sánchez Mateos (c) "AI4EUROPE - How is Trustworthy AI manifested in these flagship projects?" by Paul Lukowicz

Figure 3: Trustworthy AI Webinar at Adra-e

European Convergence Summit 2024

SustainML together with the TrustWorthy AI Cluster participated at the European Convergence Summit 2024 organised by Adra-e project, on 19 June 2024.

More specifically, SustainML was presented, among the other sibling projects, at the ADR Exhibition, which allowed EC-funded projects and other initiatives to showcase the technologies emerging at the frontiers of the disciplines to outline promising future paths for ADR by exhibiting demonstrations of interaction between at least two of the three technologies.

The European Convergence Summit (ECS) 2024 is a high-level event that aims to bring together influential figures from various backgrounds to support the co-programming of the Artificial Intelligence Data and Robotics (ADR) partnership, define orientations for ADR research and innovation in Europe concerning socioeconomic issues, and build a consensus among stakeholders. The overarching theme of the event will be the impact of ADR on energy/CO2 reduction.

²⁴<https://adra-e.eu/events/trustworthy-ai-landscaping-verifiable-robustness-and-transparency>

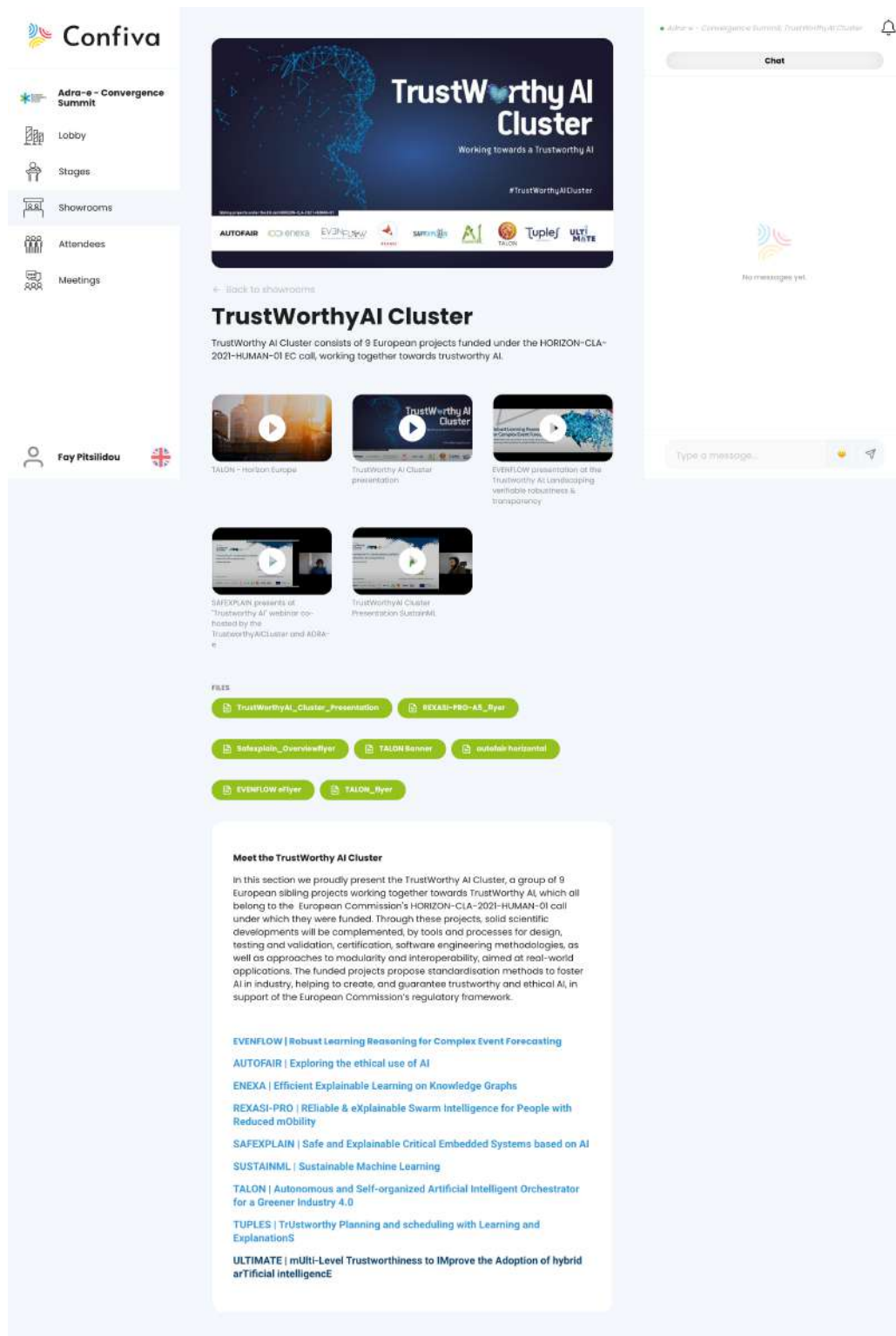


Figure 4: Trustworthy AI Cluster virtual booth at European Convergence Summit 2024

2.1.2 Cross-reference and presence in social networks

As stated before, part of the joint communication efforts of each project in the cluster focuses on the active promotion of the other sibling projects through coordinated social media campaigns. By cross-referencing and sharing updates, breakthroughs, and events from all nine projects, the cluster ensures increased visibility and engagement for the collective initiatives. This collaborative approach amplifies the overall impact of their research on trustworthy AI, reaching a wider audience and fostering a unified message.

Below are some examples of this cross-collaboration to promote the cluster's projects.

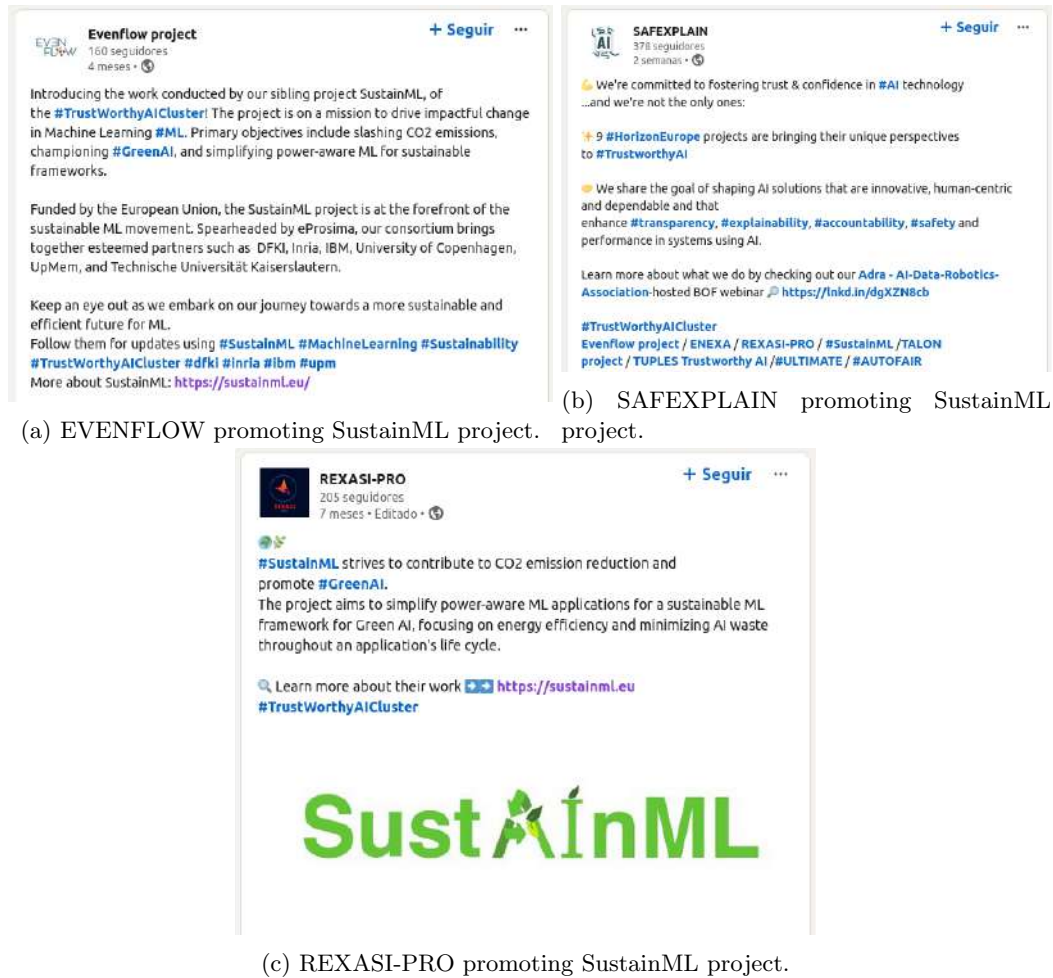


Figure 5: Trustworthy AI Cluster sibling projects posts promoting SustainML.

3 Research collaborations

3.1 ASAP conference

DFKI presented a paper funded by SustainML titled *FieldHAR: A Fully Integrated End-to-end RTL Framework for Human Activity Recognition with Neural Networks from Heterogeneous Sensors* [1] on

the 34th IEEE International Conference on Application-specific Systems, Architectures and Processors (ASAP 2023) in Porto ²⁵ and has received positive interests.

3.2 Diehl Aviation

Based on the gained research knowledge in the scope of SustainML, specifically on deploying machine learning models in energy-constrained environments, DFKI gained the attendance of Diehl Avionics which led to an industry-research partnership project. The accompanying neural network model training techniques on compressing model size and complexity enable research towards embedding neural network models into the safety-critical and energy-constrained environment of avionics. Currently, the guidelines of the avionics sector prohibit the embedding of any AI-based controls in safety-critical systems, though there is a strong urge for such solutions to enhance the avionic sector's potential. DFKI not only supports Diehl Avionics through providing knowledge, rather the mutual exchange of two viewpoints on different problem settings and the resulting implementation of prototype systems covering the collected requirements sums up the collaboration.

4 Collaboration with ROS community

The partnerships with the Robot Operating System (ROS) community are intended to bring the developers of the ROS community closer to the SustainML framework to leverage this framework the main design tasks prior to ML application development. The methodology to be followed in this collaboration is based on the use of three major channels:

- ROS Discourse
- ROS 2 Technical Steering Committee (TSC)
- AI Integration Working Group

These are explained below in a section dedicated to each of them.

4.1 ROS Discourse

ROS Discourse ²⁶ serves as a dynamic forum within the ROS community are able to share use cases, announcements and other news related to ROS, rather than technical questions. It is a place for users to interact with each other by showing the progress of their implementations, proposals for new working groups and research results in order to improve the ROS ecosystem.

EPROS is actively engaged in this channel, committed to providing regular updates on developments performed within the SustainML project, with a specific focus on the SustainML framework tool. Our collaboration with the ROS community aims to ensure that the roadmap of new ROS-compatible technologies is useful and potentially exploitable by ROS end-users and developers.

In the initial stages of the project, , forum activity has been limited, as outlined in *Deliverable 7.4 - Report on communication, exploitation and dissemination - Initial*. The phase of engaging the ROS community to use the SustainML framework in their AI/ML design and development process is scheduled for the upcoming project phase, when proven innovation results and stable and testable products resulting from the innovation will be made available.

²⁵<https://www.asap2023.org>

²⁶<https://discourse.ros.org>

4.2 ROS 2 Technical Steering Committee (TSC)

The ROS 2 Technical Steering Committee (TSC)²⁷ is the organism comprising representatives of companies, organisations, and ROS 2 community in charge of setting the guidelines for the development of ROS 2. These organizations are committed to collaborate in the development of ROS 2, and have the responsibility to define the direction of the project.

EPROS as a member of the ROS 2 TSC has the right to vote on actions taken affecting the governance of ROS 2. Therefore, EPROS has a privileged position to promote the SustainML project at dedicated TSC meetings and hence reach the ROS 2 community.

Moreover, because the representatives of the organizations that comprise the ROS 2 TSC have a wide experience in the robotics industry, and especially in ROS 2, it is possible to get first-hand feedback on all the results of the SustainML project.

4.3 AI Integration Working Group

Before the initialization of the project, eProsima submitted a proposal for the creation and leadership of a new working group that aims to create a community of ROS users who apply ML technologies in systems developed with the ROS 2 framework. Thus, it would be possible to closely monitor the use cases of AI in robotics in order to present SustainML as an innovative solution that has a number of benefits compared to traditional ML applications design processes.

During the first phase of the project, eProsima has been leading the AI Integration Working Group. The primary objective is dedicated to empowering Machine Learning technologies for ROS 2 and applying Artificial Intelligence to various use cases. Through collaborative synergy and the exchange of insights, the group is dedicated to showcasing the potential of SustainML framework for robotics applications based on ML in the ROS community.

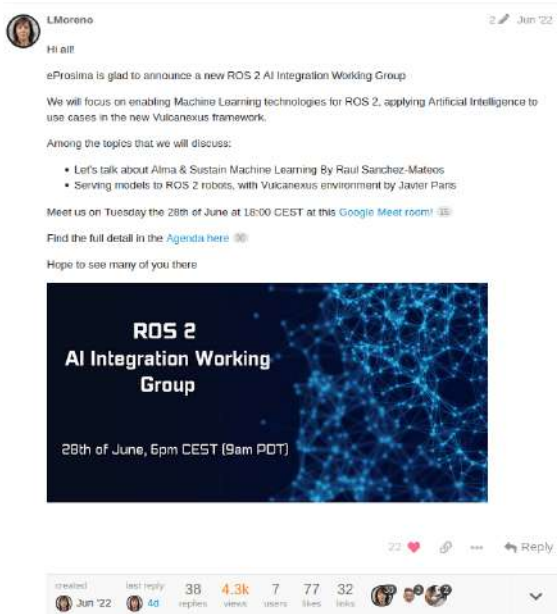
For detailed information regarding the working group agenda, open public Google Meet meeting room, and meeting discussions, please visit the AI Integration Working Group topic in ROS Discourse²⁸. Also note that every meeting is recorded and the session recording is publicly available in eProsima's Vulcanexus YouTube channel²⁹.

For a comprehensive overview of the group's topics and interactions, please refer to Figure 6.

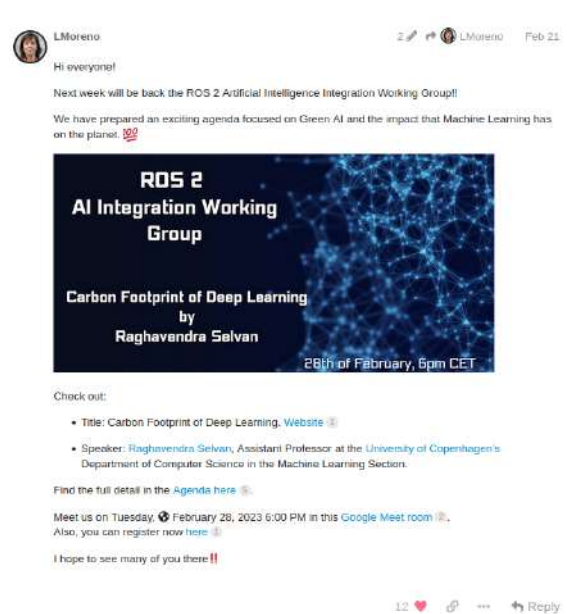
²⁷<https://docs.ros.org/en/rolling/Governance/ROS2-TSC-Charter.html>

²⁸<https://discourse.ros.org/t/ros-2-ai-integration-working-group>

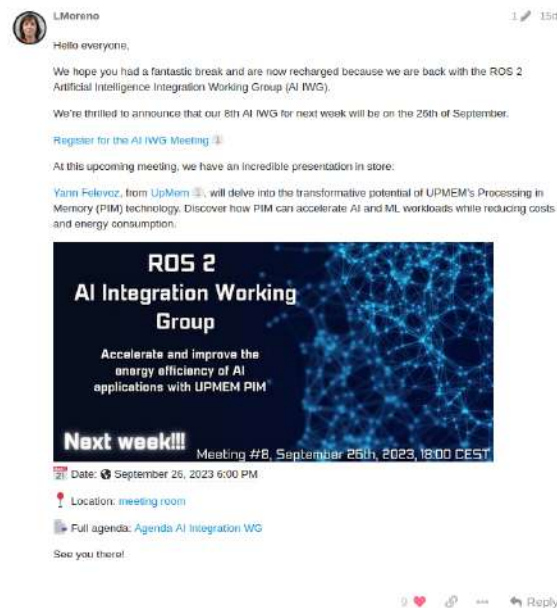
²⁹<https://www.youtube.com/@vulcanexus9399>



(a) AI Integration Working Group first post



(b) AI Integration Working Group - meeting #4



(c) AI Integration Working Group - meeting #8

Figure 6: ROS Discourse posts

5 National collaborations from individual partners

5.0.1 GenoPIM

GenoPIM³⁰, funded by the French National Research Agency (ANR), is the national counterpart to BioPIM and focuses on transforming genomics applications through the integration of high-throughput DNA sequencing and processing-in-memory (PIM) technologies. The project, with UPMEM as part of the project consortium, aims to revolutionize the energy-intensive processing of genomics data, making it faster, more energy-efficient, and cost-effective. GenoPIM can benefit from SustainML's activities by drawing insights from sustainable machine learning practices, particularly in optimizing energy efficiency. As GenoPIM delves into co-designing algorithms with PIM for genomics applications, SustainML may provide valuable perspectives on energy-efficient computing solutions, contributing to the overall goal of enhancing genomic analysis while ensuring sustainability.

5.0.2 ODYSSAI

ODYSSAI aims to revolutionize embedded AI applications in constrained environments through the development of a modular edge computing system. Leveraging open-source software and hardware technologies, ODYSSAI focuses on achieving significant energy efficiency by implementing specialized AI accelerators within optimized hardware platforms. This project aligns with the goals of SustainML, as it explores sustainable practices in AI and machine learning. SustainML's expertise in energy-efficient computing can contribute valuable insights to ODYSSAI, particularly in optimizing the energy efficiency of edge computing solutions.

5.1 Synergizing Chip Design Evolution for Enhanced Computational Efficiency

In a collaborative convergence of cutting-edge projects, BioPIM, ODYSSAI, STRATUM, and SustainML collectively explore diverse avenues of UPMEM chip design evolution. With a shared goal of accelerating performance and minimizing energy consumption across varied applications, these projects contribute significantly to identifying optimal design options for the next generation of chips. BioPIM focuses on harnessing processing-in-memory technologies for genomics applications, ODYSSAI targets modular edge computing for embedded AI, STRATUM advances technologies in complex surgeries, and SustainML pioneers sustainable machine learning practices. Together, they form a comprehensive exploration that aims to render intensive computation faster and more energy-efficient. This collaborative effort is poised to shape the future landscape of UPMEM chip design, propelling advancements that not only optimize computational speed but also energy efficiency across a spectrum of applications.

³⁰<https://genopim.irisa.fr>

References

- [1] Mengxi Liu et al. “FieldHAR: A Fully Integrated End-to-end RTL Framework for Human Activity Recognition with Neural Networks from Heterogeneous Sensors”. In: *arXiv preprint arXiv:2305.12824* (2023).