Mid-term evaluation

Title of the programme: **Ecological Safe Vehicle for green mobility**

Acronym of the programme: **EVA4green**

S4 priority area: **Mobility**

Evaluator:

Enzo Marinari

Sapienza University of Rome

Italy

1. Introduction: basic data on the project and mid-term evaluation

EVA4green is an important project, that has the main objective to develop advanced research to promote applications towards greener mobility, more ecological vehicles and safer transportation. The project has been found, at the time of initial evaluation, both very solid and potentially very useful for Slovenia. I am very happy that after the evaluation conducted in March 2019 I am able to completely confirm this initial very positive assessment.

A number of very well integrated companies and academic centers are the basis of EVA4green. There are four academic institutions: Department of Mechanical and Electrical Engineering from University of Ljubljana, the Department of Electrical Engineering and the Department of Computer Science from University of Maribor, and FINI from Novo Mesto. The participating industrial companies are Sieva, Kolektor Group, Hidria, TPV, RLS, NELA, Podkrižnik and Cosylab. Also the Slovenian National Building and Civil Engineering Institute is part of the project. Coordinator of the project is Sieva.

The project is both composite and homogeneous, in a very interesting mix of activities, all based on the common goal of promoting, as from the title, a new, green, human oriented approach to mobility. Different aspects are selected as important, even crucial, in the development of a new paradigm for green and human oriented mobility, and they

have been developed with remarkable success. The project deals with both the main drive and the auxiliary drives of the vehicle, trying to obtain gains making it more ecological and fit to a modern world. It takes care of mechatronic assemblies in the vehicle, and of systems and components that have effect to vastly improve comfort and safety. In this scenario, among other activities, components for a next generation internal combustion engines are developed. They could turn out to be key elements to achieve low emissions of pollutants, high efficiency and high specific power, and they could potentially conquer significant global market shares. Also, and this is what I believe is a crucial part of the project, a large amount of attention is given to the development of electric mobility. The projects aim at developing new electric drive systems with supporting power electronics converters, also featuring a cooling system and devices for protection. Some of the developed systems (mechatronics assemblies) can be used in both electric and hybrid vehicles, and have been some of the main focuses of the project. For example, a lot of attention has been given to systems of electric motor, gears and position sensors. Also I have found that development and research about components and integrated systems for safety and comfort has led to important results. It has focused on actuator systems and on important lightweight components.

2. Assessment of the progresses

2.1. General observations with regard to the on- site visit

The midterm report was clear and well written. It looked, after comparing to the research development I observed during my visit, to describe very fairly and thoroughly the remarkable progresses that have been obtained. The visit was very well organized and effective. I got very sensible summaries of all the relevant features of the research progresses obtained by EVA4green, in its multiple facets and developments. A dramatically interesting tour in Kolektor has given clear examples of the research style, of the prototyping and of the testing (I found remarkable, for example, the process of development of the concept and of the details of the new pumping system, that I hope will reach the success that it seems to deserve). Time usage was optimized. Each development was described from different points of view. Many different researchers were involved in discussing the results, both from industries and from academic bodies, giving hints about how strong and positive the synergies in the project have been. Answers to detailed questions were always very precise, sometimes given by the

researcher that had done the work in first person, even when she or he was not the designated speaker. This was very enjoyable and highly useful.

2.2. Key highlights

I will give here some details about the ones I perceived as the most visible results obtained by the project. It should be stressed that a further, added value, was the global framework designed by the total of the results obtained (let me quote a relevant, famous, important statement, by stating that the total is, in this case, far more than the sum of the parts).

RDP 1.1 was dealing with "concepts and models" for "COMPONENTS AND SYSTEMS FOR EFFICIENT INTERNAL COMBUSTION ENGINES", while RDP 1.2 was analyzing "samples from laboratory environment".

RDP 1.1.1: DESIGN OF A PIEZOELECTRIC PRESSURE SENSOR FOR INTERNAL COMBUSTION. An analysis of available sensors on market has been the starting point towards the design of a new sensor concept, for which it is important to notice that a patent application was filed. FEM mechanical simulations have allowed to define a detailed design scheme. During tests of the engine samples were working, but not performing as hoped. It was not possible to have them complying with target specifications. The concept was abandoned, and a further, new one, was designed. I am very positive about the flexibility of this research team, and about the fact that they have been able to get new ideas to solve in a brilliant way a difficult situation. Also, here the importance of synergies emerges. The industrial partner has been closely working with the Department of mechanical engineering in Ljubljana University to identify the main mechanisms that cause aging of pressure sensors (this has been based on the development of methods to induce aging effect and methods for evaluating its extent).

RDP 1.2.1: VALIDATED PROTOTYPE OF THE PIEZOELECTRIC PRESSURE SENSOR. Since the sensor design has been completely changed after the negative results obtained in the first, preliminary studies, the new design had to be implemented from scratch: rules for the construction of the sensor, optimization, drawings and the needed and crucial documentation were prepared. Testing and validation of samples have been developed and analyzed, both in the laboratory and on test vehicles. These tests were positive (and I underline the very positive effort that has been done to go from the first failure to the success of a completely redesigned scheme): the measured output was this time meeting target requirements, and the design was functional and appropriate to the goals set by the project. Testing was also useful to develop new practices and schemes that allow a more accurate evaluation of the sensor performances:

this has also been useful to define procedures towards the serial production of the sensor. I consider the results obtained for the piezoelectric sensor as one of the (many) remarkable outcomes of the EVA4green project.

RDP 1.1.2: DESIGN OF AN OPTICAL PRESSURE SENSOR FOR INTERNAL COMBUSTION ENGINE The feasibility of a cost effective miniature optoelectronic system for measurements of pressure in internal combustion engines has been analyzed. The very interesting system was based on miniature optical sensors manufactured at the tip of an optical fiber, together with an optical signal interrogator. A three wavelengths systems based on laser diodes, a four wavelength interrogator based on commercially available LED and an interrogator based on a tandem interferometer were analyzed. Also a Fabry-Pérot approach to pressure sensor design was analyzed.

RDP 1.2.2: PROTOTYPE OF AN OPTICAL PRESSURE SENSOR FOR INTERNAL COMBUSTION ENGINES Measurements in a laboratory environment, on common rail systems and on a real engine were carried out. The system base on an optical interrogator based on a tandem interferometer looked promising, and was analyzed in good detail, also on a real engine. Test tools have been developed. The needed optical fiber system has been fully specified. Even if the study of this system did not lead to a final determination of a commercial product I think one should stress that there was here a further very important development.

RDP 1.1.3: DESIGN OF A DUAL MASS FLYWHEEL FOR INTERNAL COMBUSTION

ENGINES The design of a viable dual mass flywheel has been finalized. The final result saves 15% of weight compared to the original piece: this is not a small gain.

RDP 1.2.3: PROTOTYPE OF A DUAL MASS FLYWHEEL FOR INTERNAL COMBUSTION ENGINES Documentation and 3D modeling of an improved dual mass flywheel have been finalized. A physical version has been tested in the laboratory of the Department of Mechanical Engineering.

RDP 1.1.4: DEVELOPMENT OF A PUMP FOR INJECTING WATER INTO THE CYLINDERS OF AN INTERNAL COMBUSTION ENGINE This is a success that I consider one of the most important, maybe groundbreaking results of the project. This is a very new design and operational mode, and the project has been successful enough to be able to define all necessary production steps.

RDP 1.2.4: VALIDATION OF THE PROTOTYPE OF A PUMP FOR INJECTING WATER INTO THE CYLINDERS OF AN INTERNAL COMBUSTION ENGINE Long tests have confirmed stable operation of the new pump in water for up to ten thousand hours. The design of the main components has been optimized, and manufacturing technologies, testing procedures and

testing devices have been improved. The pump has reached a level of quality that can already allow it to be put on the market. What is crucial is that this innovative concept could turn out to have a large number of uses in very different applications: this is an impressive potential result.

RDP1.1.5: DEVELOPMENT OF A SOLENOID ACTUATOR FOR VARIABLE VALVE TIMING AND CYLINDER DEACTIVATION A two pin solenoid has been developed. Prototypes have been tested in real life conditions on long times. The possibility of realistic production has been shown. A very advanced development level has been reached.

RDP 1.2.5: VALIDATION OF A SOLENOID ACTUATOR FOR VARIABLE VALVE TIMING AND CYLINDER DEACTIVATION The very positive results of the product development have led to an optimized design of the prototype, that it would be possible to manufacture in large quantities without major problems. Prototypes have been built. They have allowed to test the life expectancy of a solenoid, and to show feasibility in a real life industrial environment. Different technologies have been analyzed, and this has allowed to minimize potential manufacture costs.

RDP 2.1 was dealing with "research on technologies" for "COMPONENTS AND SYSTEMS FOR MAIN DRIVE ELECTRIFICATION", while RDP 2.2 was analyzing "prototypes in a simulated operational environment".

This part of the project is, I believe, as a general approach surely one of the most relevant, and I will come back to that in the following. There is a world- wide revolution in the field of electric automotive transportation, and games are completely open: this is a field where the chances of the country to be a global, leading player, are very large. The work package was dedicated to develop of components and systems for the electrification of the vehicle. New technologies, materials, products, and processes in the field of electrification of the vehicle were evaluated. System voltages going from 48 V to 600 V we considered and analyzed.

Two new electric machines have been conceived and detailed, and a multi-phase machine was designed to be applied in safety-critical applications. Also a three-phase permanent magnet synchronous machine for 48V was designed and analyzed. A number of results have been obtained and are important: DC/DC converters were analyzed, and fuses/circuit breakers were studied. Several laboratory prototypes were developed.

Also this work package was involved with the study and the design of effective rotors and stators, that could allow to increase the efficiency of electric motors. Last, but surely not least, the research was centered around developing an effective liquid heat exchanger, to improve the performances of the cooling system.

Prototypes were developed in a simulated development environment. The results have led to plans to go towards preparing components and systems prototypes for the vehicle electrification (always by analyzing system voltages in the range 48V to 600V). The project has the goal of producing useful prototypes, both in a laboratory environment and in a simulated operational environment, and to design and validate the production processes. The project has not lead yet to finalize this part, but is has advanced fast in this direction. This research path will eventually lead to prototypes of two electric drives, of two DC/DC converters, and of a number of fuse/circuit breaker designs for both LV and HV applications. It will also allow to develop and test new materials and tools and to finalize and operate the new cooling system that has been conceived.

RDP 3.1 was dealing with the "development of concepts and models" for "MECHATRONIC ASSEMBLIES AS AUXILIARY SYSTEMS IN VEHICLES", while RDP 3.2 was analyzing prototypes.

This part of the project has been involved, and has obtained significant results, about all of the subjects discussed in the original proposal. This consistency of the EVA4green project, all along its lines and developments, has been I believe a very valuable and important asset. I will come back to this.

This work package has been successful in its large majority. The only problem has occurred with design of integrated sensors for regulating the rotary electrical machinery. There were problems due to the quality of the laboratory equipment to produce reliable magnetic track, and to patent restrictions on manufacturing processes. Optimization of the process and a few iterations have allowed also in this case to reach success: laboratory sensors samples were eventually successfully produced.

Prototypes and functional demonstrators of components in mechatronic assembly have been obtained as promised. Functional demonstrators of the components of the mechatronic system and intelligent mechatronic assembly have been successfully achieved.

RDP 4.1 was dealing with the "development of concepts and models" for "SYSTEMS AND COMPONENTS FOR SAFETY AND COMFORT", while RDP 4.2 was analyzing prototypes.

This work package has reached its objectives, and has brilliantly done what was promised.

First a manual on lightweight components has been developed. The manual is designed as an electronic base of knowledge in the field of lightweight design, and it is accessible in an internal

network to all researchers of the company that developed it. Even if I would not qualify this development as applied research but more like a service to such research, what seems really important is that this is a crucial tool that will be very useful in the following (I should recommend maybe that it becomes as open as a tool as possible, to maximize its utility for all the researchers in the field).

Solutions concerning lightweight design were developed, together with new virtual evaluation methodologies. Problems connected to corrosion and technology were analyzed. A very important issue that was clarified is connected to how to prepare lightweight materials and, what is maybe even more important, how to connect different parts together.

A more theoretical research, mainly based on numerical simulations, allowed to clarify and confirm the validity of the selected design concepts. The project analyzed in detail, among other concepts, a passenger compartment area, by stressing the potential for safety and comfort improvement.

Also the practical parts of manufacturing of lightweight components have been analyzed: it is important to quote for example the cross car beam, the trailing arm and an actuator for safety and extended comfort.

The concept of a cross car beam was analyzed thanks to software packages for mass optimization. A hybrid concept of the cross car beam with magnesium parts was implemented and evaluated. High temperature measurements allowed to collect input data. Static loads were evaluated thanks to numerical simulations. The problem of innovative mechanical joining of different materials, namely steel and magnesium alloys, was analyzed.

When designing the new trailing arm welding, a new part to the body demanded accurate studies. Also, an important new sensor for determining the level of corrosion was developed and manufactured. A consistent weight reduction was reached thanks to the new materials.

A new device controlling the gas pedal was developed.

2.3. Changes

The project execution was very faithful to the original plane, and I appreciated that very much. When some difficulties have been encountered they have been dealt with very high competence and they have been solved in a very positive way. In some sense difficulties have helped to reach even better results and change, in this sense, have been positive. This has been a very serious and coherent project.

3. Role of the partners in the project

All partners have played the role that was assigned to them in the initial proposal. Things have worked smoothly. This has been very beneficial, and has allowed to obtain and finalize a large number of useful results.

4. Internal and external communication

Communication among partners has been very good. I did not detect any sign about problems that have slowed down the work. The scientific output (that should also be on scientific journals of high standards) of the project should continue even (and mainly) after results have been obtained: it is clear that publishing is possible only when the work has been done, but it is also very important to stress that high profile publishing is not optional in a research project like the present one (this concerns not only academic partners but also industrial partners). I will come back to this point.

5. Assessment of dissemination and exploitation of the project results

The transparency of the project looks high, even if I did not get much input about dissemination and outreach. Maybe now that the project has led to solid and stable result, developing some further outreach activities would be appropriate and useful. Also it would be very useful to make the information gathered in the “manual” as public as possible (it is clear that there are a number of constrains, and I have in mind here as much openness as compatible with such constraints): the “manual” could indeed turn out to be spectacularly useful to develop research in the field.

6. Assessment of quality of main scientific achievements

The project has led to very remarkable results. Basically all of its products look of very high value, and deeply innovative. I will surely quote here, just as individual examples, the pressure sensors, the injecting pump (that could really lead to a number of game changing applications) and some of the devices for motor electrification. The quality has globally been very high.

7. Cooperation between public and private partners and assessment of synergies

The different partners have worked together very effectively. I have found really remarkable the way in which cooperation has worked in this project. This was clear also, for example, during the questions and answers sessions, where answers were given somehow, in a very clear and explanatory way, by the different partners that had been working together on a single issue, always succeeding in explaining all the relevant features.

It is clear that advanced competences have cross fertilized. This project has had a very large added value.

8. Concluding remarks and recommendations

This project has been a real success story, and has produced a large added value. The results have been in large part potential important innovations, and the plan of the project, as detailed in the proposal, has been respected in full. Promises have been kept very carefully. When difficulties have been encountered, further analysis has allowed to go beyond by suggesting new approaches: in some sense difficulties have been pushing the project even further. This is remarkable, and it is indeed the signature of an excellent project.

Very evident and useful synergies have appeared: the project has shown a very high added value.

The project has led to good publications (mainly papers submitted to conferences), and now that the main results have been assessed, many more publications will come (hopefully in journals of high standing). So I am satisfied about this. Still, I feel there is something that is worth stressing. In a project that invests public money in applied research (that very frequently goes with basic research, that can also play a crucial role in such a context: just think about the development of the “web” as we know it today during the highly speculative studies of fundamental physics at CERN in Switzerland, or the development of the theoretical structure of the Internet during the DARPA USA project), publishing is not an additional, marginal condition, but one of the crucial points of the game. All the country wins if good papers show the brilliant ideas developed during the project, and in this way such ideas are there to stay. Also, publications are a way to make the work done known everywhere in the world, valuable, and make possible to assess it. This clearly concerns both industrial and academic researchers that both should aim towards a very high level of publications.

I believe that electrification is one of the main points today, and the project has delivered about this. I feel that further investments in this direction would be appropriate, and that this is where a brave and forward looking thinking could change the game. The projects have shown that there are very specific competences of very high level (including the ones that have been

applied here to improving conventional combustion engines), and they could be used to make the country a leading player. In these days, there is a revolution in the field, and Slovenia could really be promoted to a main protagonist if brave enough to use these opportunities. I strongly advise, after having analyzed the brilliant results of this project, to try and walk some steps in this direction. Also in this changing world, dedicating efforts to developing tools and devices dedicated to public (typically electric) transportation, always as a part of a global effort where private transportation plays a crucial role, could be a smart choice, and many of the very advanced ideas that I have seen developed here could be important.