The project actions were grouped with reference to the following macro activities:

- **Action 1**: Project management
- **Action 2**: Assessment actions
- **Action 3**: Experimental investigations and technological development
- **Action 4**: Implementation
- **Action 5**: Life Cycle Risk Assessment
- **Action 6**: Communication and dissemination
- **Action 7**: Communication plan after end of project
- **Action 8**: General project monitoring

The activities performed and the main results achieved with regard to the more specifically technical actions (Actions from 2 to 5) are briefly illustrated below.

The main purpose of the assessment activities in **Action 2** was to define the operative context of the project, validating its relevance and evaluating beforehand the feasibility of future implementations.

The ELV (End of Life Vehicles) and ELT (End of Life Tyres) management systems in use in Italy and other (European and non-European) countries were investigated in **Action 2.1** in light of the current laws and directives. ELT recycling and energy recovery technologies were analysed and compared. The technological features were determined by analysing the available literature and in the course of several technical visits to plants located in Italy. We could thus confirm, also on the basis of the quantitative data taken into account, that ELT recycling may effectively contribute to achieving the EU objectives for ELT exploitation, and that in this perspective context their use in bituminous conglomerates for road paving is particularly advantageous from the technical and environmental points of view.

The quantitative analysis of the direct and indirect environmental effects associated with the various ELT treatment and use techniques was developed in the scope of **Action 2.2** by applying Life Cycle Assessment (LCA) methods. In particular, with reference to data in literature, we compared the cases of disposal in landfill (taken as reference although no longer permitted by the laws in force), use as fuel in cement factories and mechanical comminution for making granulates and powders. The analysis focused on two main parameters, namely GWP (Global Warming Potential) and PED (Primary Energy Demand). We could thus assert that the mechanical treatment solution is particularly advantageous from an environmental point of view, as confirmed by the lower GWP values, and especially indicated for ELT management given the potentially high available volumes.

The LCA results were assessed further in **Action 2.3** by considering the production and laying technologies of bituminous conglomerates containing ELT powder for road construction and maintenance. In particular, referring to specific techniques derived from prior investigations carried out by 'Politecnico di Torino', we took two technologies into account, namely wet technology (related to gap-graded and open-graded mixtures, respectively) and dry technology, the latter deriving from the reuse of powder. These were compared with the production and laying techniques used in current practice by evaluating the GWP and PED above, and other relevant environmental parameters. The results show that the impact of the dry technique is similar to that of the standard processes, while techniques deriving from the use of binders made with wet methods are particularly advantageous from the energy and environmental point of view, above all in the case of gap-graded mixtures. Finally, we observed that further benefits can be assumed if the analysis is extended to paving maintenance.

Action 2.4 focused on surveying the stone aggregates (first use and recycled) which can be potentially used in order to evaluate the actual feasibility of laying conglomerates containing ELT powder in the scope of the TYREC4LIFE project. For this purpose, we analysed the data supplied by quarries located in the north of Italy, with particular focus on those located in the Piedmont region. Some of the

aggregates identified at this first step were tested in laboratory to characterise their physical-chemical properties and to evaluate the main volumetric and mechanical quantities of gap-graded bituminous mixtures prepared with them. By comparing the obtained results with the most recent technical standards applicable to the road construction sector, we can conclude that bituminous mixtures having features suited for road construction use can be formulated using the currently available aggregates. More than acceptable results were obtained also in the case of recycled aggregates deriving from the new waste-to-energy plant of the city of Turin.

In the same spirit, in **Action 2.5** we investigated the availability of ELT powder for road constructions in Italy. For this purpose, we took samples from seven different treatment plants and carried out laboratory tests to determine their physical-chemical properties. We could therefore observe the presence of a direct connection between the ELT treatment process type and the size distribution of the powder. Various comminution operations can be conveniently applied before grinding (e.g. multiple crushing and intermediate granulation), in particular, in order to obtain finer products, characterised by a higher specific surface capable of promoting powder and bitumen interactions. The IPA and BTEX contents, particularly relevant for the purpose of determining harmful atmospheric emission potentials, are determined according to the type of treated tyres. The value of these parameters is significantly reduced if truck tyres only are accepted. Finally, we found that cryogenic treatment may be a valid option to obtain fine powder. However, problems of compatibility with the bitumen may occur due to the small specific surface since the particles resulting from this process are highly smooth. Furthermore, such products have higher IPA and BTEX content values, thus generating possible problems of environmental compatibility.

The project evaluation actions were completed in **Action 2.6**, aimed at listing the companies located in the province of Turin which could be involved if the ELT reuse technologies in road paving are disseminated on local level also following the results obtained by the TYREC4LIFE project. The investigations focused on businesses operating in the road constructions sector and those dealing with the collection and treatment of waste of various nature and were used to create a GIS (Geographic Information System) database to be used in the future as well in order to promote dissemination and follow-up activities.

The experimental investigation and technological development actions were performed in the scope of **Action 3** with the main objective of developing the technological and scientific bases on which to establish the subsequent implementation activities.

Action 3.1 focused on the study of bituminous binders of asphalt rubber type, prepared in laboratory by using ELT powder deriving from various production processes (at ambient temperature, cryogenic and waterjet). These binders were tested to evaluate viscosity (which significantly influences bituminous mixture production and compacting) and the main rheological properties (complex modulus and phase angle) which control the mixture performance in operation. The results were compared with the acceptability limits of the most recent technical standards and were used to identify possibly relationships between the physical and morphological features of the powders and the rheological properties of the corresponding binders. Finally, part of the experimentation was dedicated to studying the features of asphalt rubber binders with particular paraffin product additives for reducing viscosity. The knowledge acquired as a whole in the action is coherent with specialised technical-scientific literature, and was thus considered for the preliminary evaluation of the binders used in the later laboratory and field experiments within the TYREC4LIFE project.

In view of the construction of the pilot road sections required during the project implementation step, **Action 3.2** was developed to evaluate beforehand in laboratory the features of different types of bituminous mixtures containing asphalt rubber binder. The stone aggregates and binders, selected during Actions 2.4 and 3.1 and subjected to suitable preliminary characterisation, were combined to

make four gap-graded mixtures (standard, with low binder content and coarse) and two dense-graded mixtures (coarse and fine). Investigations focused on compatibility (with Marshall presses and revolving platform and compacting roller), volumetry (maximum theoretical density, void percentage, voids in aggregate mixture and voids filled with bitumen), empirical mechanical properties (Marshall stability and indirect traction before and after submersion in water), performance features (wheel-tracking and semi-circular bending) and emission potential (gaseous emission release test and analysis). The results were found to be compatible with the requirements contained in the most recent technical standards and were organised in a database for subsequent formulation and acceptance of the mixtures to be used in the pilot sections.

Action 3.3 focused on developing a full size mixer prototype for producing bituminous mixtures with dry technology. This was deemed necessary for the success of the TYREC4LIFE project because the experimentations documented in literature indicate the frequent occurrence of breakdown in use deriving from the lack of uniformity of the mixtures in mixtures of this type. During **Action 3.3.1**, the mixing system was designed taking the most advanced technological solutions available today into account and the results achieved in a laboratory study during which the various mixtures (for wearing course and base) and the effect of the addition of powder of various size (ultrafine and granulate) by means of different procedures (hot and cold procedures) were evaluated. Experimentation took machinability, volumetric and mechanical properties of the mixtures into account to identify formulation criteria and to define the final prototype layout. The prototype was physically made in **Action 3.3.2**, and completed by means of calibrations and reliability tests.

The prototype will be used for full size test paving in order to evaluate the possible use of additives for reducing laying temperatures (**Action 3.4**) and to acquire information on the functional and structural properties of the mixtures made using dry technologies also in relation to compacting method optimisation (**Action 3.5**). These activities will be developed in 2015.

Action 3.6 will also be carried out in 2015, by means of full size test paving using bituminous mixtures made with asphalt rubber (wet technology). In order to extend the contents of the TYREC4LIFE project, different types of mixtures from those used for the pilot experiments will be used during these paving operations.

The implementation actions, in the scope of **Action 4**, were provided to fulfil the demonstration requirement of the TYRE4LIFE project, as set forth in the LIFE+ programme.

The object of **Action 4.1** was to design and perform road construction and maintenance operations on the infrastructures of the Metropolitan City of Turin using bituminous conglomerates containing asphalt rubber binders. The technical specifications were defined taking similar documents available in literature and the results of previous actions into account. Two bituminous mixtures were designed (one of gap-graded type and one of dense-graded type) using the materials available to the contractor. The composition and compacting properties of the mixtures were checked by means of suitable test fields and these mixtures were used to make 3 cm thick wearing courses on SP 503 Baio Dora (September 2014, about 8900 m^2 of paving) and on SP 53 San Giorgio (October 2014, about 9400 m^2 of paving). The first case was the completion of the new infrastructure, while the second case was a routine maintenance operation. During the works, experimental tests were carried out to verify the composition and volumetry of the mixtures and to evaluate the main mechanical properties and emission features. The results of these tests were coherent with requirements and expectations and were conductive to the full approval of the works.

The activities in scope of **Action 4.2** also referred to the implementation of paving maintenance operations with bituminous mixtures containing ELT powder. They were designed as innovative solutions to be adopted for supplementary maintenance on an extra-urban road of the town of Settimo

Torinese (Via Brescia). Upon the advance evaluation of the actual damage to the existing paving, three sections on which to operate were defined. The operation will consist in laying a gap-graded wearing course (similar to the one of SP 503), a dense-graded wearing course with asphalt rubber SAMI (Stress Absorbing Membrane Interlayer) underneath and a reference wearing course of standard type. These activities are scheduled to be carried out in 2015.

In the scope of the project, the demonstration paving on the pilot sections of the Metropolitan City of Turin and in the town of Settimo Torinese will be appropriately monitored, as described in Actions 4.3 and 4.4, to examine adherence and regularity (**Action 4.3**), as well as the structural features and noise (**Action 4.4**). The activities started after completing the operations identified on the SP 503 and 53 roads and will continue to the end of the project.

Action 5 does not relate to implementation strictly speaking and is instead an overall evaluation on the sustainability of the technologies analysed in the TYREC4LIFE project. It focuses on evaluating the potential impacts on the environment and health of workers determined by the use of road construction and paving maintenance techniques in which ELT powder is used. For this purpose, analysis instruments were used to create an innovative Life Cycle Risk Assessment (LCRA) system.

During the preliminary evaluations, the Life Cycle Analysis (LCA) was performed by comparing the environmental performance of bituminous mixtures containing ELT powder (made using wet and dry technologies) with traditional type mixtures. The results deriving from a case study on extra-urban road and expressed in terms of GER (Gross Energy Requirement) and GWP (Global Warming Potential) have demonstrated that the use of mixtures made with wet technology may provide significant benefits in terms of energy saving, environmental impact and reduction in the use of resources. These advantages are guaranteed only if the bituminous mixtures are designed and laid according to rules of best practice with the corresponding possibility of reducing wearing course thickness and maintenance frequency. In the case of dry technology, it is has been found that the eco-profiles of the corresponding paving are approximately equivalent to those of a road paving of traditional type. Further analysis with LCA instruments will be carried out during 2015 with specific reference to full size paving experiments carried out on the roads of the Metropolitan City of Turin and in the town of Settimo Torinese.

With regards to Risk Analysis (RA), a first comparison of the various technologies examined was performed during the course of previous studies which focused on the HQ (Hazard Quotient) and on the IELCR (Individual Excess Life Cancer Risk) parameters. They will be developed with specific reference to the TYREC4LIFE project paving experiments in 2015.