European Commission

New Solutions in Energy Supply

SMALL HYDROELECTRIC PLANTS

Guide to the Environmental Approach and Impact Assessment

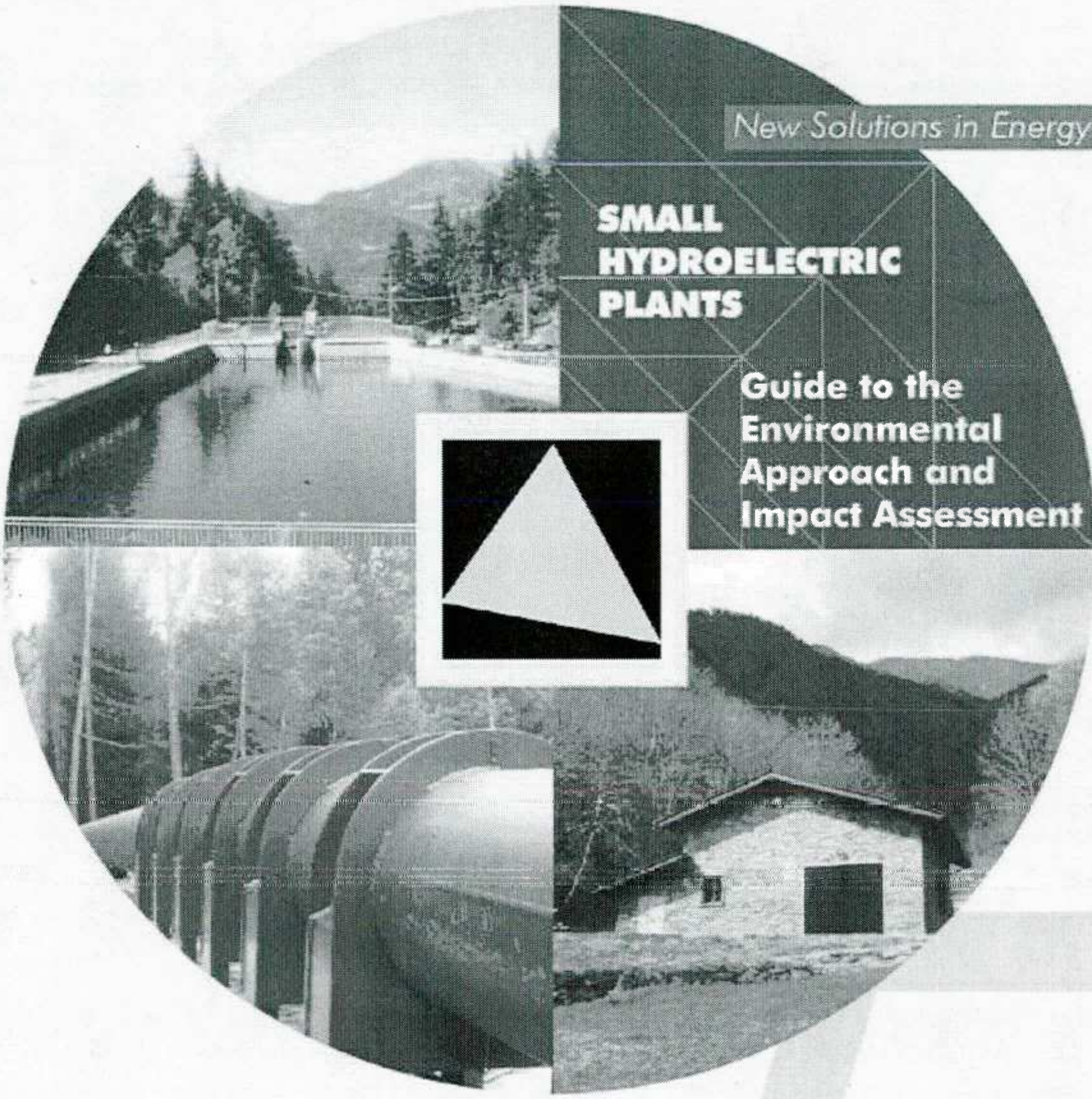

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TABLE OF CONTENTS

1 INTRODUCTION

1.1 HOW THE IDEA OF THIS GUIDE WAS BORN

The idea of this guide was born in 1998 after the completion of a small hydropower plant in the northern part of Italy (Rino small hydropower plant): this plant was realised inside an area particularly sensitive from the environmental point of view, Adamello Natural Park; the choices made during the design stage were the result of a close examination of the environmental problems connected with the realisation in a park and were agreed upon with the relevant authorities, especially the mitigation and compensation measures.

Thanks to its innovation and its peculiarity, the project received the financial support of the European Commission within the THERMIE A programme.

The experience acquired in the plant realisation, the results achieved, especially in terms of acceptability of a small hydropower plant in a sensitive area and in terms of collaboration with the relevant authorities and, last but not least, the appreciation by environmental officers of the adoption of the multi-criteria analysis for the environmental impact assessment, suggested to the authors the idea of creating a tool to favour the discussion about the environmental impact of small hydropower plants on as objective as possible basis and of placing the said experience acquired at disposal of both small hydropower plants designers and public officers in charge of authorisation issuing.

The results is the present guide prepared within the frame of the THERMIE B Programme - project nr. DIS/2037/98-IT and at now included in 5th Framework Programme.

The guide, especially with reference to the structure of chapter 5, widely utilises the results and the general lines set out in the project nr. 4.1030/z/97-010 "Ecological evaluation criteria in case of hydropower projects referring to the EU-EMAS regulation" carried out within the ALTENER programme.

1.2 WHY A GUIDE TO ENVIRONMENTAL IMPACT ASSESSMENT OF SMALL HYDROPOWER PLANTS

Everyone working in the small hydropower field knows how many obstacles are put on the road of the implementation of a small hydropower plant. One of the highest ones is represented by the environmental impacts connected to the construction and operation of a small hydropower plant.

The guide is meant to be the contribution, based on real experiences, of the people who work in the renewable energy source field to a correct facing the environmental problems by means of:

- Suggestion of typical and well tried methodologies to reduce environmental impact both in the design and construction phase.
- Evaluation of the actual benefits brought to environmental parameters, but to technical and economical parameters too, by the actions devised to improve the project.
- Sensitivity analysis, in order to give the designer precious directions about the parameters which mainly influence the project from every standpoint (technical, economical, environmental).

As at the roots of whatever choice (design, construction and authorisation issuing choice) the analysis of the environmental impact is present - analysis always complex and often too subjective - a large part of the work carried out has been devoted to the implementation of a analysis system which could meet the following criteria:

- Objectivity, that is inter-subjective verifiableness;
- Capability in analysing complex phenomena;
- Contemporary acceptability by environmentalists, investors and officers in charge of authorisation issuing;
- Compatibility with the main evaluations methods already used and usually less complex than the here proposed one.

The most important aim of the guide is in fact to supply a mean as objective as possible to carry out Environmental Impact Assessment, based on objective criteria linked to measurable quantities (energy, velocities, areas, volumes and so on) in order to avoid any unacceptable, arbitrary or too subjective evaluation.

This aim has been achieved by means of the multi-criteria analysis.

This method allows to compare on a objective basis different design solutions, including the so called "zero alternative", (that is no small hydropower plant realisation). The method is based on the definition of a list of criteria (economical, technical, environmental and so on) and in assigning to each of them a weight chosen by the evaluator. A suitable mathematical model compares in many different ways both the weighted and the not weighted criteria. The final result is a series of indexes, including a global one, which allows the evaluator to know which project is the best from the environmental point of view. Obviously different evaluators choose different weights for the same criteria (the ecologist will give high weight to environmental criteria, the investor to the economic ones and so on), but the principle of the method is to supply a first objective basis for a further deeper discussion.

1.3 WHY A SOFTWARE TO ENVIRONMENTAL IMPACT ASSESSMENT OF SMALL HYDROPOWER PLANTS

The multi-criteria analysis is a method rather complex to be used without the aid of a specific software to make calculations. The great number of the criteria usable in a close enough examination of the environmental problems connected to a small hydropower plant realisation requires the creation of a software to help designers and evaluators carry on a meaningful and satisfactory analysis of the problem.

The implementation of specific software to carry out Environmental Impact Assessment by means of the multi-criteria or multi-dimensional analysis as above described was another aim of the work carried out.

A fundamental tool included in the software is the possibility to carry out sensitivity analysis of the indexes coming from the multi-criteria analysis. So you can immediately see which project is the best when the value of the weight of each group of criteria (economical, technical, environmental) varies.

Another interesting characteristic of the work is to make immediately evident which parameters are to be varied to make the small hydroelectric plant more easily acceptable from the environmental point of view. So, for example, if the multi-criteria analysis shows that, keeping the weights constant, the height of the diversion works or the reduction in water velocity are the parameters which make the project undesirable with respect of other design solutions, you can see how you must modify these parameters to reach a major environmental acceptability.

1.4 WHO THE GUIDE AND THE SOFTWARE ARE INTENDED FOR

The guide and the software are intended for both designers and competent authorities dealing with small hydropower plants problems.

The guide supplies to designers a tool to evaluate the environmental effects of the choices made in order to allow the adoption of the mitigation and compensation measures necessary to improve the acceptability of small hydropower plants from the environmental standpoint.

The creation of a tool which could represent a common objective basis for the discussion on environmental problems of the small hydropower plants was the main intention of the authors: they hope that competent authorities can introduce this tool in their evaluation procedures in order to achieve a better transparency in decision making and to allow a deeper discussion on small hydropower plants which in spite of everything by now represent one of the most important renewable energy sources and which are worthy of better consideration.

1.5 STRUCTURE OF THE GUIDE

First of all, in chapter 2 the guide briefly describes the main characteristics of the small hydropower plants, with particular care to those elements which have a major effect on environment. This description is principally intended for layman and it hasn't any claims to be exhaustive, but it wants only to introduce the matter.

Secondly, a short walk into environmental impact assessment is taken in chapter 3, in order to define its main general characteristics.

Then the elementary actions connected to the realisation of a small hydropower plant are more closely examined in chapter 4.

Chapter 5 deals with the description of the predefined criteria proposed in the software to describe by means of measurable quantities the actions and impacts qualitatively stated in chapter 4.

Chapter 6 supplies a description of the technologies suitable to reduce the negative impacts paying particular attention to the bioengineering methods and the multipurpose use of the water resources.

The following chapters are devoted to describe the method used for the environmental impact assessment of small hydropower plants, that is the multi-criteria analysis. At first some general information about the algorythms involved is given; then, even to describe the use of the software implemented to facilitate the assessment, a real example is fully developed and commented.

1.6 FEW WORDS ABOUT THE AUTHORS

Fabrizio MAZZETTO is Associate Professor of Agricultural Machinery and Mechanisation at the University of Milan. Graduated in Agricultural Sciences, he then achieved an Agricultural Engineering PhD degree carrying out researches on the use of renewable energy technologies in agriculture. Besides energy problems, his research activities now deals with development of mathematical models and decision support systems for farm machinery selection and use; automation of field operation and precision farming practices. His work is documented by about 120 published papers.

Luigi PAPETTI is a chemical and hydraulic engineer graduated at Politecnico of Milan. He joined Studio Frosio in 1990 and since then is involved in small hydropower plants design and supervision paying particular attention to the environmental problems.

Bernhard PELIKAN is Professor at "Department of Water Management, Hydrology und Hydraulic Engineering" at the „University of Natural Resources“, Vienna, Austria. He is also a Judgement expert of hydropower exploitation and flood protection and Senior expert of the "Austrian association promoting small hydro power".

He deals with problems connected with water resources exploitation, small hydropower and related specific environmental problems since 1980.

In 1998 he was appointed Extraordinary University Professor.

2 THE SMALL HYDRO PLANTS

2.1 FOREWORD

In this chapter we at first try to give a definition of small hydropower plant and of the different scheme typologies. Then we take a short walk into the main elements of a small hydropower plant, with particular reference to those ones which affect the environmental impact. A more detailed description of the elements constituting a small hydropower plant can be found in the "Layman's Guidebook on how to develop a small hydro site" available on the web site: http://europa.eu.int/en/comm/dg17/public.htm of the European Commission.

2.2 DEFINITIONS

There is no consensus in European Union on the definition of small hydropower. Some countries as Portugal, Spain, Ireland and now Greece and Belgium accepted 10 MW as the upper limit for the installed capacity. In Italy the limit is fixed at 3 MW. In France the limit is established at 8 MW and UK favour 5 MW. Hereunder any scheme with installed capacity of 10 MW or less will be considered as small. This figure is adopted by five member states, the European Commission and UNIPEDE (International Union of Producers and Distributors of Electricity).

ESHA (European Small hydropower Association) has finally stated the following definitions, referred to the installed capacity at the plant:

- Micro hydro plants up to 100 kW
- Mini hydro plants up to 500 kW
- Small hydro plants up to 10,000 kW

From the technical standpoint, this definition is certainly acceptable, but from an economical and environmental point of view a size up to 10 MW could raise serious perplexities.
Suffice it to think especially of many existing low head schemes to point out that large weirs or basins with a remarkable environmental impact make it difficult to accept a definition of small hydro based on installed power only.

2.3 TYPOLOGIES

Small hydroelectric plants, but large too, could be divided in three main categories, depending on the different use of water, which heavily affects their technical and environmental characteristics:

1. Run-of-river plants
2. Pondage plants
3. Reservoir plants

Hereunder the definition stated by IEC (International Electrotechnical Commission) is reported.

- A run-of-river hydro plant uses the river flow as it occurs, the filling period of its own reservoir by the cumulative water flows being practically negligible. The most part of small hydropower plants are run-of-river plants because of the high construction cost of a reservoir.
- A pondage hydro plant is a plant in which the filling period of the reservoir based on the cumulative water flows permits the storage of water over a period of a few weeks at the most. In particular, a pondage hydro plant permits the cumulative water flows to be stored during periods of low load to enable the turbine to operate during high load periods on the same or following days. Some small hydropower plants fall in this typology, especially high head ones with high installed capacities (> 1.000 kW).
- A reservoir hydro plant is a plant in which the filling period of the reservoir based on the cumulative water flows is longer than several weeks. It generally permits the cumulative water flows to be stored during the high water periods to enable the turbine to operate during later high load periods. As the operation of these plants requires the construction of very large basins, no small hydropower plant practically fall in this typology.

2.4 STRUCTURES FOR WATER STORAGE AND WATER DIVERSION

DAMS

The dam is a fundamental element in the conventional hydraulic schemes, where it is used to create a reservoir to store water and to develop a head. In a relative flat terrain a dam, by increasing the level of the water surface, can develop the head necessary to generate the required energy. The dam can also be used to store, during the high flow seasons, the water required to generate energy in the dry seasons. Notwithstanding, due to the high cost of the dam and its appurtenances, they are seldom used in small hydro schemes.

If the scheme is connected to an isolated net and if the topography is favourable, a dam can be included to store excess water when the flow is high or the demand low to make it available at times of low flow or increased demand.

Where a reservoir built for another purpose - irrigation, water abduction to a city, flood regulation, etc. - already exists, it can be used by constructing a plant at the base of the dam to turbine the compatible water flows.

WEIRS

The large majority of small hydro schemes are of the run-of-river type, where electricity is generated as far as a discharge larger than a minimum – the minimum required to operate the turbine - flows by the watercourse. In these schemes a low diversion structure is built on the streambed to divert the required flow whilst the rest of the water continues to overflow it. When the scheme is large enough, this diversion structure becomes a small dam, commonly known as a weir, whose role is not to store the water but to increase the level of the water surface so the flow can enter the intake.

According to the ICOLD (International Committee of Large Dams) a dam is considered "small" when its height, measured from its foundation level to the crest, does not surpass 15 m, the crest length is inferior to 500 m and the stored water is under 1 million cubic meters. These parameters are important, reckoning the complicated administrative procedures associated with the construction of large dams. The large majority of small dams equipping small hydro schemes are of the gravity type, commonly founded on solid rock and where the stability is due to its own weight. If the dam is less than 10 m high it can be built on earth foundations, but allowable stresses must not be exceeded and the possibility of piping due to seepage under the dam must be minimised, through the use of aprons or cut-offs.

SPILLWAYS

In countries like the south of Europe, with a clear difference between dry and wet season flows, flood flows can have catastrophic effects on whatever structure is built in the stream. To avoid damage the excess water must be safely discharged over the dam or weir. For this reason carefully designed overflow passages are incorporated in dams as part of the structure. These passages are known as "spillways". Due to the high velocities of the spilling water, some form of energy dissipation is usually provided at the base of the spillway.

The commonest type of spillway is the overflow gravity type. Basically it is an open channel with a steep slope and with a rounded crest at its entry. To minimise the pressure on the surface of the spillway the profile of the crest should follow the same curve as the underside of the free-falling water nappe overflowing a sharp crest weir. This trajectory varies with the head, so the crest profile is the right one only for the design head.

Shaft or "glory hole" spillways are rarely used in small scale-hydro. A shaft spillway incorporates a funnel-shaped inlet to increase the length of the crest, a flared transition which conforms to the shape of the nappe as in the overflow spillway though it is sometimes stepped to ensure aeration, a vertical shaft and an outlet tunnel that sometimes has a slight positive slope to ensure that at the end it never flows full.

ENERGY DISSIPATORS

The discharge from a spillway outlet is usually supercritical and so may produce severe erosion at the toe of the dam, especially if the streambed is of silt or clay. To avoid such damage, a transition structure known as a stilling basin must be constructed through the formation of a hydraulic jump, where the water flow changes from supercritical to subcritical.

LOW LEVEL OUTLETS

Low level outlets in small hydropower schemes are used to perform, together or independently, the downstream release and the evacuation of the reservoir, either in an emergency or to permit dam maintenance. In general a low level-conduit with a cone valve at the exit or a sliding gate at the inlet is enough to perform both functions. At the exit, if the flow is supercritical, the provision of energy dissipators should be considered.

2.5 WATERWAYS

INTAKE STRUCTURES

The Glossary of Hydropower Terms – 1989 defines the intake as "a structure to divert water into a conduit leading to the power plant".

Following the ASCE Committee on Hydropower Intakes, the water intake is defined as a structure to divert water to a waterway – not specifying what type of waterway: a power channel or a pressure conduit – and reserving the word forebay or power intake to those intakes directly supplying water to the turbine, via a penstock.

A water intake must be able to divert the required amount of water into the power canal or into the penstock without producing a negative impact on the local environment and with the minimum possible head loss. The intake serves as a transition between a stream that can vary from a trickle to a raging torrent, and a controlled flow of water both in quality and quantity. Its design, based on geological, hydraulic, structural and economic considerations, requires special care to avoid unnecessary maintenance and operational problems that cannot be easily remedied and would have to be tolerated for the life of the project.

A water intake designer should take three criteria into consideration:

- Hydraulic and structural criteria common to all kind of intakes.
- Operational criteria – e.g. percentage of diverted flow, trash handling, sediment exclusion, etc. that vary from intake to intake.
- Environmental criteria – fish diversion systems, fish passes – characteristics of each project.

Notwithstanding the large variety of existing intakes, these can be classified according to the following criteria:

- The intake supplies water directly to the turbine via a penstock. This is what is known as power intake or forebay.
- The intake supplies water to other waterways – power canal, flume, tunnel, etc. that usually end in a power intake. It is known as a conveyance intake.
- The scheme doesn't have any conventional intake, but make use of other devices, like siphon intakes or "French intakes" that will be described later on.

In the multipurpose reservoirs - built for irrigation, drinking water abstraction, flood regulation, etc. the water can be withdrawn through towers with multiple level ports, permitting selective withdrawal from the reservoir vertical strata or through bottom outlets.

POWER INTAKES

The power intake is a variant of the conventional intake, usually located at the end of the power canal, although sometimes it can substitute it. Its hydraulic requirements, by the fact that it has to supply water to a pressure conduit – the penstock – are more stringent that those of a conveyance intake.

In the small hydropower schemes, even in the high head ones, water intakes are horizontal, followed by a curve to an inclined or vertical penstock. The design differs if the horizontal intake is component of a high head or a low head scheme.

In low head schemes a good hydraulic design – usually more costly than a less efficient one – makes sense, because the head loss through the intake is comparatively larger related to the gross head. In high head schemes, the value of the energy lost in the intake will be small relatively to the total head and the cost of increasing the intake size to provide a lower intake velocity and a better profile may not be justified.

MECHANICAL EQUIPMENT

One of the major functions of the intake is to minimise the amount of debris and sediment carried by the incoming water, so trashracks are placed at the entrance to the intake to prevent the ingress of floating debris and large stones. A trashrack is made up of one or more panels, fabricated from a series of evenly spaced parallel metal bars. If presumed that the watercourse in the flood season may entrain large debris, is convenient to install, ahead of the ordinary grill, a special one, with removable and widely spaced bars.

When the river entrains heavy debris, floating booms located ahead of them complement trashracks. The simplest boom consists of a series of floating pieces of timber connected end to end with cables or chains. However modern booms are built with prefabricated sections of steel and plastic supported by steel cables. Its location is critical, because its inward bowed configuration does not lend itself to a self-cleaning action during flood flows.

A horizontal platform above high-water level should be provided to facilitate the cleaning operation. On unattended plants operated by remote control, mechanical rakers must be used. The mechanical raker can be designed to be triggered either on a timed basis or on a head differential basis. The second one uses a sensor to detect the drop in head across the trashrack.

An accumulation of trash on the trashrack creates an increased differential head across the trashrack. The raker begins when a predetermined differential head is reached.

SEDIMENT MANAGEMENT AT INTAKES

Location of intakes is particularly important in this respect. Open channels have a tendency to deposit sediments on the inner sides of bends, but when the intake is located at the outer side of the bend floodwaters may damage it. To prevent this problem, the best solution is locating the intake structure along a relatively straight section of the river. Designing an intake for sediment exclusion can be a noxious approach to permit small fish protection. For example limiting the velocity at the screen approach to permit small fish to escape can result in deposition of sediments up to the point of blocking the entrance. Locating the intake entrance on a non-erosionally bedrock streambed would prevent the sediment's entrance but the construction costs will be increased.

GATES

In every small hydropower scheme some components, by one or another reason - maintenance or repair, avoid the runaway speed on a turbine shutdown, etc. - should be temporarily isolated. Some of the gates and valves suited to the intakes for small hydro systems include the following:

- Stoplogs made up of horizontally placed timbers
- Sliding gates of cast iron, steel, plastic or timber
- Flap gates with or without counterweights
- Globe, rotary, sleeve-type, butterfly and sphere valves

For low pressure the simplest type of gate is a stoplog; timbers placed horizontally and supported at each end in grooves. Stoplogs cannot control the flow and are used only to stop it. If the flow must be stopped completely, such as when a repair is needed downstream, the use of two parallel sets of stoplogs is recommended.

Gates and valves control the flow through power conduits. Gates of the sliding type are generally used to control the flow through open canals or other low-pressure applications. This is the type of flow control used on conveyance intake structures where, if necessary, the flow can be stopped completely to allow dewatering of the conduit.

Small sliding gates controlling the flow can be raised by using either a wheel-and-axle mechanism or a hydraulic cylinder.

The radial gates, conceptually different, are a method of forming a moveable overflow crest and allow a great control of headwater and tailwater.

OPEN CHANNELS

The flow conveyed by a canal is a function of its cross-sectional profile, its slope, and its roughness. Natural channels are normally very irregular in shape, and their surface roughness changes with distance and time.

For the same cross-sectional area, and channel slope, the channel with a large hydraulic radius, delivers a larger discharge. That means that for a given cross-sectional area, the section with the least wetted perimeter is the most efficient hydraulically. Semicircular sections are consequently the most efficient. A semicircular section however, unless built with prefabricated materials, is expensive to build and difficult to maintain.

Actual dimensions have to include a certain freeboard (vertical distance between the designed water surface and the top of the channel bank) to prevent water level fluctuations overspilling the banks.

In the conventional hydropower schemes and in some of the small ones, especially those located in wide valleys, when the channels must transport large discharges, the excavated ground is used to build the embankments, not only up to the designed height but to provide the freeboard, extra height necessary to foresee the height increase produced by a sudden gate closing, the waves or the rains collected by the canal itself under heavy storms.

These embankment channels although easy to construct are difficult to maintain, due to the wall erosion and the aquatic plant growth. The velocity of water in these unlined canals should be kept above a minimum value to prevent sedimentation and aquatic plant growth, but below a maximum value to prevent erosion.

In the high mountain schemes the canal is usually built in reinforced concrete, so much that the environmental legislation should require to be covered and revegetated.

Sometime to ensure that no seepage will occur, the canal is lined with geotextiles sheets, so preventing the landslide consequent to the wetting of clayey material.

PENSTOCKS

Conveying water from the intake to the powerhouse – the purpose of a penstock – may not appear a difficult task, considering the familiarity of water pipes. However deciding the most economical arrangement for a penstock is not so simple. Penstocks can be installed over or under the ground, depending on factors such as the nature of the ground itself, the penstock material, the ambient temperatures and the environmental requirements.

A penstock installed above ground can be designed with or without expansion joints. Variations in temperature are especially important if the turbine does not function continuously, or when the penstock is dewatered for repair, resulting in thermal expansion or contraction. Usually the penstock is built in straight or nearly straight lines, with concrete anchor blocks at each bend and with an expansion joint between each set of anchors.

The anchor blocks must resist the thrust of the penstock plus the frictional forces caused by its expansion and contraction, so when possible they should be founded on rock. If due to the nature of the ground, the anchor blocks require large volumes of concrete, thus becoming too expensive, an alternative solution is to eliminate every second anchor block and all the expansion joints, leaving the alternate bends free to move slightly. In this case it is desirable to lay the straight sections of the penstock in steel saddles made to fit the contour of the pipe and generally covering 120 degrees of the invert.

TAILRACES

After passing through the turbine the water returns to the river through a short canal called a tailrace. Impulse turbines can have relatively high exit velocities, so the tailrace should be designed to ensure that the powerhouse would not be undermined. Protection with rock riprap or concrete aprons should be provided between the powerhouse and the stream. The design should also ensure that during relatively high flows the water in the tailrace does not rise so far that it interferes with the turbine runner. With a reaction turbine the level of the water in the tailrace influences the operation of the turbine and more specifically the onset of cavitation. This level also determines the available net head and in low head systems may have a decisive influence on the economic results.

2.6 ELECTROMECHANICAL EQUIPMENT

POWERHOUSE

In a small hydropower scheme the role of the powerhouse is to protect from the climatological hardships the electromechanical equipment that converts into electricity the potential energy of water. The number, type and power of the turbo-generators, its configuration, the scheme head and the geomorphology of the site would condition the building topology.

Integrating turbine and generator in a single waterproofed unit that can be installed directly in the waterway means that a conventional powerhouse is not required. Siphon units provide an elegant solution in schemes with heads under 10 meters and for units of less than 1000 kW installed.

Otherwise to mitigate the environmental impact the powerhouse can be entirely submerged. In that way the level of sound is sensibly reduced and the visual impact is null.

In low-head schemes the number of Kaplan turbine configurations is very large (pit, in S, right angle, etc.). In medium and high head schemes powerhouses are more conventional with an entrance for the penstock and a tailrace. This kind of powerhouse are sometimes located in a cave, either natural o excavated for the purpose.

The powerhouse can also be at the base of an existing dam, where the water arrives via an existing bottom outlet or an intake tower.

HYDRAULIC TURBINES

The purpose of a hydraulic turbine is to transform the water potential energy in mechanical rotational energy.

Turbines can be classified in two main different ways: on the basis as how the flow proceeds in the turbine or according to the specific speed.

Hereunder we deal only and briefly with the first criterion.

The potential energy in the water is converted in mechanical energy in the turbine, by one of two fundamental and basically different mechanisms:

- the water pressure can apply a force on the face of the runner blades, diminishing in value as it proceeds through the turbine. Turbines that operate in this way are called reaction turbines. The turbine casing, being the runner fully immersed in the water, must be strong to withstand the operating pressure. Typical reaction turbine are Francis, Kaplan and propeller turbines.
- The water pressure is converted into kinetic energy before entering the runner.

The kinetic energy appears in the form of a high-speed jet that strikes the buckets, mounted on the periphery of the runner. Turbines that operate in this way are called impulse turbines. As the water after striking the buckets drops into the tail water with little remaining energy, the casing can be very light and serves the purpose of preventing splashing.

Impulse turbine are Pelton, Turgo and cross flow turbines suitable for high and medium head schemes.

Both reaction and impulse turbine can be installed with vertical or horizontal axis. In any case the type of turbine to be installed heavily affects the size and the shape of the powerhouse and the kind of the relevant civil works.

SPEED INCREASERS

When the turbine and the generator operate at the same speed and can be placed so that their shafts are in line, direct coupling is the right solution; virtually no power losses are incurred and maintenance is minimal. Turbine manufactures will recommend the type of coupling to be used, either rigid or flexible although a flexible coupling that can tolerate certain misalignment is usually recommended.

In many instances, particularly in the lowest power range, turbines run at less than 400 rpm, requiring a speed increaser to meet the 1000-1500 rpm of standard alternators. In the range of powers contemplated in small hydro schemes this solution is usually more economical than the use of a custom made alternator.

It's worth mentioning speed increasers even in this guide, because they are often the main source of noise coming from a powerhouse. An incorrect design of speed increaser usually causes a lot of operation and environmental problems (noise, oil leakage).

GENERATORS

Generators transform mechanical energy into electrical energy. Although most early hydroelectric systems were of the direct current variety to match early commercial electrical systems, nowadays only three-phase alternating current generators are used in normal practice. Depending on the characteristics of the network supplied, the producer can choose between synchronous generators and asynchronous generators.

The working voltage of the generator varies with its power. The norm is generate at 380 V up to 1400 kVA and at 6000/6600 for bigger installed power. Generation at 380 V permits to use standard distributor transformers as outlet transformer and use the generated current to feed into the plant power system. Generating at high voltage require an independent transformer HV/LV to supply the plant services.

TURBINE CONTROL

Turbines are designed for a certain net head and discharge. Any deviation of these parameters must be compensated by opening or closing control devices such as the wicket-vanes or gate valves to keep constant, either the outlet power, the level of the water surface in the intake or the turbine discharge.

In schemes connected to an isolated net, the parameter to control is the runner speed, directly related to the frequency. The generator becomes overloaded and the turbine slowed-down when the demand increases. In this case there are basically two approaches to control the runner speed: controlling the water flow on the turbine or keep the water flow and the electric load constant by adjusting an electric ballast load connected to the generator terminals.

In the first approach, speed (frequency) regulation is normally accomplished through flow control; once a gate position value is calculated, the actuator gives the necessary instruction to the servomotor, which results in an extension or retraction of the servo's rod. To ensure that the rod actually reaches the calculated position, feedback is provided to the electronic actuator. These devices are called "speed governors".

In the second approach it is assumed that, at full load, constant head and flow, the turbine will operate at designed speed, so maintaining full load on the generator; this will run at a constant speed. If the load decreases the turbine will tend to increase its speed. An electronic sensor, relying on the measure of frequency, detects the deviation and a reliable and inexpensive electronic load governor, switch on preset resistances and so maintain the system frequency accurately.

The controllers that follow the first approach do not have any power limit. The Electronic Load Governors, working according to the second approach, hardly ever exceed the 500 kW.

Turbine control devices are worth mentioning because conventional and more diffused speed governors are composed by a combination of oil driven hydraulic devices which can be a source of water pollution in case of oil leakage.

It must be said that in the last years manufactures have made big efforts to reduce the risk of oil leakage from every part of the equipment.

SWITCHGEAR EQUIPMENT

In every country the electricity supply regulations place a statutory obligation on the public electric utilities to maintain the safety and quality of electricity supply within defined limits.

The independent producer must operate his plant in such a way that the utility is able to fulfil its obligations. Therefore various associated electrical devices are required inside the powerhouse for the safety and protection of the equipment.

Switchgear must be installed to control the generators and to interface them with the grid or with an isolated load. It must provide protection for the generators, main transformer and station service transformer. The generator breaker, either air, magnetic or vacuum operated, is used to connect or disconnect the generator from the power grid. Instrument transformers, both PTs and CTs, are used to transform high voltages and currents down to more manageable levels for metering.

The generator control equipment is used to control the generator voltage, power factor and circuit breakers.

HEADWATER AND TAILWATER RECORDERS

In a hydro plant provisions should be made to record both the headwater and tailwater. The simplest way is to fix securely in the stream a board marked with meters and centimetres in the style of a levelling staff but someone must physically observe and record the measurements. In powerhouses provided with automatic control the best solution is to use transducers connected to the computer via the data acquisition equipment.

Nowadays measuring units – a sensor – record the measurement variable and convert it into a signal that is transmitted to the processing unit. The measurement sensor must always be installed at the measurement site, where the level has to be measured – usually subject to rough environmental conditions and of difficult access – whereas the processing unit is usually separated and placed in a well protected environment easily accessible for operation and service.

OUTDOOR SUBSTATION

The so-called water-to-wire system usually includes the substation. A line breaker must separate the plant including the step-up transformer from the grid in case of faults in the power plant. PTs and CTs for kWh and kW metering are normally mounted at the substation, at the connecting link between the plant-out conductors and the take-off line to the grid. In areas with very high environmental sensitivity the substation is enclosed in the powerhouse, and the transport cables leave it over the penstock.

Lightning arrestors for protection against line surges or lightning strikes are usually mounted in the substation structure.

3 General Remarks on the Environmental Impact Assessment

3.1 Foreword

In this short guide we don't intend to examine closely how an Environmental Impact Assessment must be carried out, because this matter is out of the scope of the guide.

Nevertheless it's appropriate to give some remarks about it, in order to face the specific matter of the small hydropower plants Environmental Impact Assessment in a correct way.

3.2 What is an Environmental Impact Assessment

A simple definition of the Environmental Impact Assessment is not quite easy. The Council Directive 85/337 of June 27, 1985, gives the following - and just a little bit tautological - definition: "The environmental impact assessment will identify, describe and assess in an appropriate manner ..... the direct and indirect effect of a project on the following factors:

- Human beings, fauna and flora
- Soil, water air and climate
- The interaction between the factors mentioned in the first and second incidents
- Material assets and cultural heritage"

The Environmental Impact Assessment is a procedure to support decisions: the impact studies can't be reduced to mere descriptions, but must come to an assessment made by the proponent of a project to supply to relevant authorities all the elements necessary to take a decision about the project. Therefore, the study must contain, stated in a scientific way, all the effects of the project on the environment. This approach raises to two important problems: the transparency of the steps which have produced the decision and the repeatability of the whole decision process.

3.3 When an Environmental Impact Assessment is Significant

As a decision process, an Environmental Impact Assessment is significant when is present a multiplicity of alternatives among which a choice is possible: different project and design alternatives must be took into consideration, including the so called "zero alternative", and the relevant impacts must be analysed.

3.4 In which Moment an Environmental Impact Assessment must be Carried out

Depending on the moment of the decision process, the Environmental Impact Assessment can have different degrees of detail: in the initial phase the assessment can be made on a preliminary design; in an intermediate phase the reference is to a more detailed feasibility study; in the last step the final design has to be took into consideration. Generally speaking the Environmental Impact Assessment should be made as "upstream" as possible in the decision process; by the other side it's evident that the information contained in a final design are very detailed and the design alternatives are often reduced to the mitigation measures, while much more degrees of freedom are allowed by the preliminary design or the feasibility study where technological or site alternatives can be still examined.

3.5 Why an Environmental Impact Assessment must be Transparent

An Environmental Impact Assessment must be always a process repeatable and therefore as transparent as possible: this is a very important requirement which must reflects in the clarity of data and in methods of approach accepted both by the proponent and the relevant authorities. The agreement of the parties involved in the process on the general methodology is quite important to force each part to follow a path made of precise and defined steps avoiding as far as possible arbitrary evaluations.

3.6 The Steps of the Environmental Impact Study

Any Environmental Impact Study (EIS) can be split in the following steps:

1) Description of the project, of the environment and of the design alternatives.
2) Determination and estimation of the project impacts on the environment.
3) Environmental Impact Assessment (EIA)

carried out by the proponent.

DESCRIPTION OF THE PROJECT, OF THE ENVIRONMENT AND OF THE DESIGN ALTERNATIVES

The description is the first step of an Environmental Impact Study. Its aim is to describe what you want to do, why, when, where, why in that site and not elsewhere.

Anyway, everything you are describing must be a material, physical, measurable characteristic, because it will be the base for the subsequent assessment step.

By the other side some *a priori* evaluations are always present even in the description step: they are not eliminable and they condition the description.

ENVIRONMENTAL COMPONENTS AND EXPECTED IMPACTS

Generally speaking, an impact can be described by means of the following elements:

a) SOURCE: it's the projected intervention (physically well defined works, human activities and planning and so on) which could produce significant effects on the environment.
b) ELEMENTARY ACTIONS: they are the elements of the intervention which generate interference on the environment around; they must be defined for the different moments of the life of the plant (construction, operation, possible failures, decommissioning). For small hydropower plants the most important of these moments is the operation one.
c) DIRECT INTERFERENCE: it's a direct alteration, describable in terms of environmental factors, produced on the environment by the projected intervention and considered in the initial phase during which it's generated by the actions of project (e.g. noise or water pollutants emissions).
d) ENVIRONMENTAL TARGETS: they are the elements - like a well for drinking water, a building where live some people, a site where live a particular specie - described by means of environmental components and which can be reached and modified by perturbations caused by the projected intervention.

DETERMINATION AND ESTIMATION OF THE PROJECT IMPACTS ON THE ENVIRONMENT

The main scope of impacts analysis phase is to compare the environment before and after the realisation of the works. In other words this phase connects the project actions with their impacts on the environment. To get the scope it's important to split the project in a set of elementary actions not only for clarity in the study, but even (and first of all) because only a good detail in the description prevents from generic, qualitative and aleatory information. The splitting into elementary actions make rising the problem of how to get a synthesis of all the information in view of the assessment phase. During the analysis phase the first problem to be faced is the statement of the significant impacts caused by the projects and the environmental targets. A remarkable help can be given by predefined lists both for actions and for impacts. In the specific case of Environmental Impact Assessment of small hydropower plants the approach by means of the said lists has been chosen.

Once the impacts relevant to the particular situation have been determined, the following step is their estimation. The estimation of the impact must be as far as possible quantitative. This is the most important aspect of the whole procedure. Very often the impacts are defined by qualitative criteria which are arbitrary and not measurable, so that an unacceptable degree of uncertainty is present before any assessment. Furthermore the impacts must be defined by criteria enough easily measurable or in a way compatible with the degree of detail of the project and with times to obtain an answer from relevant authorities about the environment acceptability of the project. So, especially for small hydropower plants, Environmental Impact Assessment it's recommendable to refer to abiotic indexes, more easily measurable than biotic ones and from which anyway these latter depend.

ENVIRONMENTAL IMPACT ASSESSMENT CARRIED OUT BY THE PROPONENT

In the assessment step we pass from the determination and estimation of the impacts, each one measured by an appropriate quantity, to an assessment of the importance of the variation foreseen for the specific environmental component.

In this phase we have to define the criteria on the basis of which we can say that an impact is more or less significant for the environment studied.

To make the passage from the previous step to the assessment step as less arbitrary as possible, it's necessary that the criteria are made clearly explicit.

The assessment phase is very delicate: it's necessary to predispose all the elements to make relevant authorities capable of taking the final decision about the project. In this phase proponent and authorities must interact and the respective duties have to be clearly defined. The proponent must predispose the environmental assessment in order to allow the relevant authorities to verify the reliability of the evaluations made and of the weighting used to carry on a sensitivity analysis. It's very important that the proponent doesn't stop the study to the description of the project and to the estimation of the impacts, leaving the assessment to the relevant authorities: it's quite better that the proponent quantifies the global effects of the project according to a methodology which allows the authorities to make their own autonomous evaluations.

To sum up, an Environmental Impact Assessment must:

- Make clearly explicit the criteria assumed as a base for the evaluation of the importance of an impact (*definition of the scale*).
- Define the importance of the environmental resources, supplying and justifying the weighting system adopted (*definition of the weights*).

The method utilised must allow to verify how the final assessment has been reached and how the final assessment varies when the different weights given to each impact varies, that is the proponent must supply a sensitivity analysis of the results of the assessment usable even by relevant authorities.

One of the main scopes of this guide is precisely this: to state a methodology on which both the proponent and relevant authorities agree and which constitutes a common basis for discussion and evaluations.

4 THE ELEMENTARY ACTIONS CONNECTED WITH THE REALISATION OF A SMALL HYDRO PLANT

4.1 FOREWORD

As we said in the chapter 3 dealing with the general information on Environmental Impact Assessment, once carried out the description of the project, the following step to be made is the definition of elementary actions connected to the realisation of a small hydropower plant.

The definition can be made at first subdividing the plant in homogenous zones, from both the environmental and technical point of view and then, within each zone, subdivide the actions by means of a time scale.

So, at first any plant has been split in the following "modules" which form and comprise all possible evaluation components which can appear concerning the different kinds of small hydropower plants:

1. General plant data
2. Multipurpose effects
3. Backwater area
4. Weir or dam
5. Powerhouse
6. Tailwater area
7. Headrace channel or penstock
8. Diversion section
9. Tailrace channel

This structure of the plant partially reflects the structure of the software implemented for Environmental Impact Assessment.

Obviously not every module has to be considered at each kind of a plant: usually the fix modules are 1, 3, 4, 5 and 6: they describe the general plant data, the weir, the areas above and below and the powerhouse. Variable parts are 2, 7, 8 and 9. Different kinds of plant lead to different combinations of the modules.

Within each module the elementary actions can be split according to a time scale:

- During construction
- During completion of works
- During operation
- During decommissioning

In this chapter we examine these actions independently from the module, in the following ones we deal with the impacts connected with the actions within each module.

4.2 ELEMENTARY ACTIONS DURING CONSTRUCTION

GEOLOGICAL SURVEYS

Usually, before the realisation of the works, during the construction design phase, some geological surveys are carried out to get more detailed information on the geological features of the foundations ground and on the groundwater flow rates in order to design special foundations or other particular cares during the works execution.

The surveys generally consist in geophysical (seismic surveys) or geo-electrical tests, often integrated with well logging in the weir and powerhouse areas to determine the stratigraphy of the ground and groundwater flow rates.

The equipment necessary to carry on these geological surveys is usually small enough to be transported by cars or small trucks.

The impact caused by geological surveys could be generated by the noise of the equipment required for well logging, but it's limited in time - usually no more than few days are required for surveys, as the area to be surveyed is small - and it can be relevant only in highly sensitive areas as for high mountain schemes or natural parks, where fauna could be disturbed by noise and by the man presence.

EXISTING VEGETATION CUTTING

Existing vegetation cutting is almost always necessary to realise a small hydropower plant.

This action is relevant especially for high head schemes with long outdoor or interred penstocks. The installation of the penstock requires the creation of a 6-8 m wide strip without vegetation. The impact is generally important both for the impoverishment of the forests and for the disfigurement of the landscape caused by visual impact of a bare strip cutting the slope.

Nevertheless it must be noted that in case of both interred and outdoor penstocks cut vegetation quickly grows up again and covers the strip created during works.

Vegetation cutting at powerhouse and weir could be necessary too, but it generally involves a small area with lower visual and environmental impact.

ENLARGEMENT OF EXISTING ROADS

The realisation of a small hydropower plant takes often place in depressed or not inhabited areas.

So to feed the work yards sometimes it is necessary to enlarge small existing roads or tracks.

Depending on the particular situation, the enlargement can have negative or positive impacts or both of them. The negative impact can rise from the visual intrusion, the necessity of tree cutting, the major disturb to animals caused by the future traffic and so on. By the other side, especially in depressed areas, (typically isolated, mountain areas) the enlargement of an existing road can represent an opportunity for increase the economy of the area with the consequent benefits for local people.

EARTH MOVING

This action can be important and in many countries, especially in protected areas, it is necessary to have special authorisations to carry out it.

Earth moving in fact can influence slopes stability and the landscape.

This action is very important in case of creation of new tailrace or headrace channel, especially for low head schemes located in flat areas because of the large volumes of earth moved, but even in high schemes with interred penstocks or with pondage or storage basins realised outside the riverbed. The earth moved represents in this case a great problem because it must be transported downward to dumping grounds with relevant costs. But from an environmental standpoint the problem of earth moving is mainly connected with landscape disfigurement.

TUNNELS EXCAVATION

The realisation of tunnels as headrace or tailrace channels is rather unusual in small hydropower plants because of the high cost of the works.

In many cases boring machines realise tunnels with cross section larger than the hydraulic needs, so that the high cost of them has no good reason to be met. Nevertheless it is sometimes necessary to excavate a tunnel. With this elementary action can be connected several impacts both negative and positive.

The negative ones concerns the problem of finding a place for the excavated rock and its reuse, the influence of the tunnel on groundwater regime, the stability of slopes in case of parietal tunnels, the creation of dusts, and so on; the positive ones are connected with the avoided visual impact with respect of other solutions for waterways.

PERMANENT FILLING MATERIAL ON SLOPES

The action is connected with earth moving. One of its problems is to find a final place of earth moved. Sometimes it is placed on slopes around the excavated areas to reduce the cost of transport downwards to dumping ground. This action has mainly negative impact related to the modification of the landscape, the stability of material on the slopes, especially just after that the material has been placed. Sometimes the action can have even positive impacts where filling material on slopes may represent a resource for improving the aspect of areas deteriorated by previous human agencies or natural causes.

EMBANKMENT REALISATION

This action is often necessary in low head schemes in plains to realise headrace channel especially in the vicinity of the powerhouse where higher is the difference between natural ground level and water surface elevation – and consequently waterways. The impact connected to this action is mainly due to the visual impact and sometimes to the interference with roads, canals and so on.

CREATION OF TEMPORARY EARTH ACCUMULATIONS

When in a small hydropower plant a pondage basin or long new canals are present large amounts of excavated material can be produced. A remarkable problem is the material stocking. It is usually placed in the area near the site creating temporary earth accumulations. Even in this case, as in some previously examined ones, the impact is mainly visual and, first of all, temporary so that it disappears with the end of the works.

TEMPORARY DISPLACEMENT OF PERSONS, ROADS, ELECTRIC LINES

Differently from many large reservoirs or dams, the realisation of small hydropower plants doesn't require displacement of person because, as we said, large basins are extremely rare in small hydropower plants. On the contrary the temporary displacement or interruption of roads is frequent, especially where penstock is installed under the roads to minimise the final visual impact. Even if the action refers to temporary situation, the negative impact can be relevant and must be taken into due account.

REALISATION OF ROADS AND SHEDS FOR THE YARD

Similarly to what mentioned talking about the enlargement of existing roads, it's necessary to feed the work site in some way so, especially in remote areas, the realisation of new roads must be foreseen. In remote areas is even necessary to build temporary sheds to lodge personnel deputed to plant construction.

About this action can be repeated the remarks made for enlargement of existing roads.

Moreover the impact connected with sheds for the yard is temporary and generally low, even if the visual intrusion can be disturbing.

WATER COURSES DREDGING

It can be present during small hydropower plants construction, especially when a pondage basin is realised inside the riverbed or when the downstream riverbed is lowered to increase the head.

The impact is certainly heavy especially for aquatic life, but sometimes it can have positive aspects when dredging involves rivers where large amounts of alluvial material are deposited at every flood occurrence with consequent increase in riverbed level and in inundation risk. So dredging can be a way for the river "maintenance".

TEMPORARY DIVERSION OF RIVERS

During the construction of a dam or a weir and their relevant intake structures it is always necessary to partially or completely divert the river from its normal course for the time needed for the works realisation. The length of diversion is generally small, a few number of meters, and can be made in several different ways: by a temporary earth dam which diverts water from the work areas; by a pipe system, placed downstream the areas to be protected, conveying water downstream and by many other ways depending on the particular site situation.

The impact of the action is always present, but with different levels of negativity depending on the diversion system. The targets of the action are mainly the aquatic life, the bed load transport regime and the water surface elevations upstream (major risk of inundation during flood events in the construction phase) and downstream (significant reduction of water levels till to complete drying up).

Nevertheless the impact has a remarkable dependence on the system of diversion: it's generally preferable a system of partial diversion like temporary dam which reduces flow cross sections without drying up any river stretch.

USE OF EXCAVATORS, TRUCKS, HELICOPTERS, CARS FOR THE PERSONNEL, BLONDINS

It's obvious at all that to realise any work you must use some machine. So the action is always present, but the targets and the level of impact are different and depend on the type of machine used. An emblematic case is the solution adopted to feed a penstock construction site. Very often the penstock runs along very steep slopes in inaccessible zones, so you can use helicopters to transport pipes and personnel on site or install a blondin or realise new roads.

Each solution has positive and negative aspects, the target is different and the best alternative depends on specific site situation.

HUMAN PRESENCE DURING THE WORKS ON SITE

As the previous one, this action is unavoidable, but even in this case the targets and the impacts can be different. In protected areas where, for example, rare species live, the impact is negative and the presence undesirable, but it can represent an important work opportunity in depressed areas which sometime coincide with protected ones.

4.3 ELEMENTARY ACTIONS DURING OPERATION

ENERGY PRODUCTION

This is undoubtedly the most important action of a small hydropower plant on the environment, even because it's the main scope of the work.

As we are dealing with a production of energy from a renewable energy source obtained by the exploitation of a local resource, several impacts are connected with the action: hereunder we list only some of the most important social and economical impacts:

- Reduction of the social and security costs connected with the hydrocarbons import.
- Reduction of the macroeconomic costs connected with the oil import.
- Reduction of the military and foreign affairs social costs.

- Reduction of the costs connected with gas and coal import.

WATERCOURSES DAMMING

As some of the following ones, watercourses damming is one of the action directly connected with exploitation of the water resource.

According to the definition ICOLD (International Committee on Large Dams) a dam is considered small when its height, measured from its foundation level to the crest doesn't surpass 15 m, the crest length is inferior to 500 m and the stored water is under 1 million cubic meters.

A large dam is not diffused in small hydropower plants schemes, except for multi-purpose schemes where the electricity production is not the main scope of the water resource exploitation.

It's undoubted that even the presence of a small dam or of a weir in a watercourse has an impact on the environment and it's one of the most important too.

Watercourses damming in fact reflects mainly on the river regime (water velocities, levels upstream and downstream of the dam, sediment transport and so on) and consequently on the whole environment around (vegetation, fauna) and on the landscape.

Beside of many negative impacts watercourses damming can have positive impacts too, connected with the consequent possibility of producing energy at times of low flow or increased demand and with the regulation of flow rates and the reduction of peak flows during flood events.

PERMANENT WORKS IN THE RIVERBED

Whatever system is used to divert water, permanent works in the riverbed are necessary to achieve this end. As the previous one this action is very important for the visual impact (which can be reduced anyway), but mainly for the disturbance to the riverine life and regime.

DIVERSION OF WATERCOURSES

This is the most important action within those connected with the exploitation of the water resource and in many countries the length of watercourses between the points of water diversion and restitution is taken as the most important parameter from the environmental standpoint.

The abstraction of water from rivers in fact affect heavily the riparian life and morphology: for this reason in the last decades a most part of countries issued laws and rules to guarantee minimal flow downstream of the diversion works.

NEW WATER BASINS

The large majority of small hydropower plants are of the run-of-river type where electricity is generated as far as a discharge larger than a minimum flows by the watercourse, so that no new water basin is necessary to operate the plant.

A little number of small hydropower plants has small water basins for day/night, weekly or, rarely, seasonal storage. The impact connected with the presence of water basins is different for basins realised in the riverbed or for artificial basins outside the riverbed. The former ones affect more heavily the river water regime, the latter ones occupy land otherwise untouched and add further artificial works to the landscape. They could both have, among others, problems connected to nearly stagnant water, but they can be used for recreation purposes, e.g. for angling, and become an attraction and a source of jobs in depressed areas.

PENSOTCKS

Penstocks can be installed over or under the ground, depending on factors as the nature of the ground itself, the penstock material, the ambient temperatures and the environmental requirements.

Interred penstocks should be generally preferred to outdoor ones, because of the smaller visual impact and interference with the environment around.

Nevertheless penstocks interment could have major geological risks connected with stability of steep slopes crossed by pipes, both during construction and operation. During operation in fact water leakage from an interred penstock could trigger landslides much more easily than an outdoor one.

NEW ELECTRIC LINES

As for penstocks a transmission line can be installed over or under ground. The problems involved are similar too. As small hydropower plants are usually connected with low or medium voltage electric grids, the eventual impact due to electromagnetic field emissions (at now these is no evidence of dangerous effects of them on human health) is negligible.

RIPRAPS

Ripraps are often an important part of the structures necessary to the diversion and tailrace works realisation. Their aim is the banks consolidation, especially in torrents, in the area just upstream and downstream of the intake and diversion works in order to avoid the erosion by water, mainly during flood events. These precautions must be taken to preserve diversion and intake works, undoubtedly the most important and delicate parts of a small hydropower scheme because they allow to divert water from the watercourse.

Ripraps are realised even at the end of tailrace channels at the junction with the recipient river and at all the other zones characterised by water stream energy dissipation. A typical case is the protection with ripraps or boulders downstream of dams' or weirs' spillways.

From the environmental standpoint ripraps represent a source of artificialisation of the landscape and can lead to new balances of the riparian vegetation and fauna. It's true that a lot of techniques of bioengineering, described in the following chapters, allow the reduction of the ripraps impact. It must be underlined that ripraps, all the necessary mitigation measures provided, can have even positive impacts due to the increased safety of the protected zones.

LEVEES

In dependence of the scheme typology, instead of ripraps, or complementary to them, levees must be realised. You can deal both with new levees and with the increase in elevation of existing ones, necessary to allow the plant operation in different hydraulic conditions. Typical is the case of the realisation of a small hydropower plant in plains: the water diversion is obtained by a weir usually small in height. Nevertheless, the presence of the weir, makes the backwater elevation higher than the natural one, especially during floods, so that an increase in existing levees elevation, once made the suitable stability checks, can be necessary in order to adjust the levees to the new water levels.

With this elementary action several impacts are connected: the visual impact of an element rising from the pre-existing landscape, the impact due to the eventual modification of the surface water flows from and to the river, the banks artificialisation and the consequent alteration of the riparian balances, but, by the other side, the increased safety of the surrounding zones protected by levees.

RETAINING WALLS FOR THE SLOPES CONSOLIDATION

This action is connected with the necessity of crossing with waterways already unstable slopes or slopes which could worsen their stability as an effect of the works execution. In the past a lot of small and big hydroelectric plants had been seriously damaged by landslides which destroyed waterways - canals and penstocks - cut into an unstable mountainside.

Walls for slopes consolidation has generally an important visual impact, even if the actual - and at this time reliable - techniques of the naturalistic engineering can reduce a lot the visual impact or even substitute the traditional rigid or semi-rigid structures with new ones with negligible impact and a comparable efficiency. The possibility of utilisation of these techniques can't be unconditioned, but must be considered case by case as a function of the characteristics of the slopes to be consolidated, of the loads on the structures and of the time required to the naturalistic engineering protection to became efficient.

FLOW RATE REGULATION

Flow rate regulation belongs to that set of actions which has higher effects on the environment. Obviously a small hydropower plant, for the fact itself of diverting from a river a certain amount of water, alters the pre-existing hydraulic regime with the effects already described in the previous paragraphs. On the contrary, flow rate regulation refers to more specific situations of plants which diverts continuously water and release it only in certain hours of the day or day of the week or periods of the year: this latter case, as previously said, is extremely rare in small hydropower plants, exception made for small hydropower plants in multipurpose schemes where the hydroelectric energy production is secondary and where the environmental problems are not specifically generated by the hydroelectric plant.

Flow rate regulation made by a small hydropower plant introduces new impacts which can be negative or positive, but however with flow rate regulation are connected aspects which can be critical. The negative impacts are the modification of the flow regime downstream of the water restitution which can be incompatible with other downstream water uses (but in this case a realisation of a regulation basin is imposed to restore the flow rate regime existing upstream of the diversion works) and which it is a stress source for the ecosystem subject to a periodic variation in flow rates characterised by a very wide range of water levels, velocity and of bed load transport too.

4.4 ELEMENTARY ACTIONS DURING COMPLETION OF WORKS

OUTER WORKS (FENCING, YARDS)

In a small hydropower plant are always present even completion works which can have significant impacts.

First of all, it's suitable better that the works are fenced in, especially open channels - which can represent a danger for accidental falls into water - but even intake and powerhouse areas where electrical equipment or moving parts (gates, trashrack cleaners and so on) are installed and where the access must be allowed to personnel only.

Fencing, when not realised with walls or when it is not very high, has generally a low visual impact and in any case suitable solutions can be adopted to get the better possible fitting to the environment around.

At the powerhouse one or more yards are realised to access to the building and to allow manoeuvring of cars and trucks of the operation personnel. The area covered by yards is always small and large enough to the manoeuvring only, so that the occupied areas and the connected visual impact is low.

TREE PLANTING

Tree planting is a completion work often imposed by relevant public authorities as a mitigation measure or as an environmental restoration: in the former case its aim is the naturalisation of the areas occupied by the new works or their partial visual hiding; in some special cases it can represent a first barrier to the eventual noise emission from the plant equipment. In the latter case - restoration - tree planting has the scope of restoring - at least numerically, where it's not possible in the former location - the trees cut during the works realisation.

This action has obviously only positive environmental impacts.

SOILS ASPHALTING AND WATERPROOFING

Road asphalting is an action included in the set of the completion works to made the plant more easily accessible. Sometimes it is explicitly required by local authorities, sometimes it is forbidden: in the former case with roads asphalting is implicitly connected a positive impact due to a more easy development of depressed areas thanks to easiness of access. Vice versa, in the latter case, asphalting is considered a source of artificialisation to be avoided, especially in areas sensitive from the naturalistic and environmental standpoint.

Soils waterproofing are works necessary in special situations, as for example at small hydropower plants with storage basins realised in very pervious areas, so that the bottom is waterproofed, in order to reduce water leakage from the basin.

Due to the high cost, soils waterproofing is always limited, so that this action, which can have significant potential negative impacts connected with the modification of the surface and groundwater fluxes - in case of wide areas are waterproofed - is generally negligible.

FISH RESTOCKING

In many countries fish restocking is one of the duties of the small and large hydroelectric plants operators. This duty is imposed because of the implicit hypothesis that a hydroelectric plant is however harmful for fish. As a way of fact a negative impact on fish has been always ascertained. Nowadays all the national laws require, obviously where it is pertinent, fish passes at the diversion works of the small hydropower plants. Nevertheless fish can suffer serious injuries or even die in the passage through turbine blades, in case of it hasn't been able to find fish pass to go downstream of the weir or dam.

Since years turbines manufacturers are designing, with interesting results, new "fish friendly" blades profiles in order to reduce the percentage of fish died passing through the turbine.

Coming back to the fish restocking, it has only positive impacts and it is generally an obligation for the whole life of the plant.

FAUNISTIC REPOPULATION

Faunistic repopulation is an action extremely rare in small hydropower plants because the works are so small and they don't usually imply an impoverishment of fauna so high that this type of action is required. Nevertheless in areas particularly sensitive from the naturalistic point of view it's convenient to carry on a restocking of the species which could be damaged by the plant realisation or which are migrated in more quiet zones during the plant construction.

4.5 ELEMENTARY ACTIONS DURING DECOMMISSIONING

PERMANENCE OF BUILDINGS AND MACHINES

A hydroelectric plant has a very long life, as testified by a number of small plants built at the first decades of '900 and at now perfectly working thank to the modernisation carried out periodically, especially to electromechanical equipment.

The probability of a plant decommissioning in the short and medium term is therefore rather low; nevertheless, if this occurrence would be taken into consideration, it would imply the permanence of the civil and hydraulic works only (intake and diversion works, canals, powerhouse) while the electromechanical equipment and the penstocks would be dismounted and the parts which still have a value would be partially recovered.

Particular care must be devoted to the permanence of works in the riverbed: if the works aren't demolished, they can't be indiscriminately abandoned, because they can be works that, some how or other, are modifying water levels upstream and downstream and therefore they must be maintained, especially if their abandonment can imply risks for the surrounding districts which are developed under the influence of the works to be decommissioned.

The situation regarding powerhouse buildings is quite different because they can be re-used for other purposes, as testified by some powerhouses transformed in museums.

To sum up, the permanence of buildings once the plant has been decommissioned can have even positive impacts (their re-use or maintenance of works which guarantee the hydraulic safety of the surrounding districts), but negative too (permanence of works in a state of increasing deterioration in areas particularly sensitive from the naturalistic and environmental point of view).

5 THE IMPACTS CONNECTED WITH A SMALL HYDRO PLANT REALISATION

5.1 FOREWORD

Going on in our review of the different steps of an environmental impact assessment, we have now to deal with the impacts connected with a small hydropower plant realisation.

As we said in chapter 4 we intend to deal with the subject following the structure of the software implemented and described later on.

In chapter 3 we remarked that it's essential to give a quantitative value to the criteria chosen to carry on the environmental impact assessment, so we are now going to describe the impacts connected with the actions described in chapter 4 by means of as far as possible measurable quantities and splitting the plant in the modules mentioned.

In this chapter we don't always make a distinction between negative and positive impacts, because in many cases the same actions or criteria can have positive or negative impacts according to a particular situation.

5.2 GENERAL PLANT DATA

ENERGY PRODUCED BY THE PLANT

This impact can be measured in GWh/year or in any other unit of energy per time. As we are dealing with the production by means of a renewable energy source, it has surely a positive impact on the environment and so can be classified as a benefit for the reasons listed in chapter 4. In some countries energy production is considered the only positive impact of a small hydropower plant.

CARBON DIOXIDE EMISSIONS AVOIDED

As all the other renewable energy sources, small hydro plays an important role, we dare say the most important role at now, in reducing the CO_2 emissions. As a reference we give in table 1 the indicative values of the reductions in pollutants, with regard to different fossil fuels, connected with the energy production from a small hydropower plant (See: Directorate General for Energy - DGXVII - The Renewable Energy Study - Annex 3 - 1994):

This impact is very important and positive, especially in view of the commitments undertaken within the Kyoto protocol.

TIME OF CONSTRUCTION

It can be measured in days, months or in any other unit of measure. This criterion can be a benefit because is related to the workers employed in the small hydropower plant realisation, but can be a cost too in areas particularly sensitive from the environmental standpoint.

INVESTMENT TO REALISE THE PLANT

It can be measured in any currency unit. In the software it's defined as a cost, because the environmental impact assessment is supposed to be carried out by the investor. It can be a benefit too, if you suppose that a higher number of workers employed is connected to a higher investment and so on. As a matter of fact it's not a criterion particularly interesting, because it is an extensive parameter, not specific to produced energy or installed capacity which will be nevertheless took into consideration by means of other criteria.

INSTALLED CAPACITY

It's usually measured in MW, kW, MVA or kVA. It's a benefit for the same reason cited

Table 1: externality estimates for fossil fuel electricity generation

		Coal		Clean Coal		Gas		Oil	
Externality	Unit	High	Low	High	Low	High	Low	High	Low
Air									
SO_2	$g(SO_2)/kWh$	22.7	2.3	2.7	0.5	0.0	0.0	13.6	1.8
CO_2	$g(CO_2)/kWh$	952.5	907.1	952.5	861.8	498.9	453.6	997.9	771.1
NO_X	$g(NO_x)/kWh$	4.1	2.7	1.8	0.2	2.7	0.1	3.2	1.4
Particulates	g(TSP)/kWh	18.1	0.1	0.9	0.0	0.1	0.0	1.4	0.2
Methane	$g(CH_4)/kWh$	0.9	0.9	0.9	0.9	leaks	leaks	1.8	1.4
Solids									
Solid waste	g/kWh	90.7	45.4	136.1	45.4	0.0	0.0	45.4	45.4
Metals		significant	0.0	small	0.0	0.0	0.0	significant	0.0

talking about energy production.

INVESTMENT SPECIFIC TO THE INSTALLED CAPACITY

It's usually measured in currency unit/MW, kW, MVA or kVA

It's an important specific criterion, in the past assumed even by European Commission to evaluate initiatives in the small hydropower plants field. It's an economic parameter and even from the environmental standpoint can be considered a benefit: the lower the specific investment is the higher the benefit is. It's a good indicator of the feasibility of an initiative. A reference value for this parameter can be 2.400 /kW: small hydropower plants with higher value are rather hardly financed.

INVESTMENT SPECIFIC TO THE ENERGY PRODUCED

It's usually measured in currency unit/kWh (or GWh)/year. It has a different meaning with respect to the investment specific to the installed capacity. For example the same small hydropower plant in a run-of-river scheme or in a pondage scheme can have roughly the same energy produced but very different values of the installed capacity and the investment specific to the energy produced. So these last two parameters must be used jointly to define a plant correctly.

WORKERS EMPLOYED DURING OPERATION

This is certainly a positive impact of the plant realisation, because a lot of plants can be realised in economically depressed mountain areas, so that the plant operation, as well as the realisation, have an important social feedback.

DIRECT SUPPLY OF LOCAL ENERGY DEMAND

A remarkable merit of all the renewable energy sources and particularly of small hydropower is the exploitation of local water resources and the production of energy near the resource itself. As we said a lot of small hydropower plants could be realised in depressed areas and the energy produced can be released even to small local electric grids and directly satisfy a large amount of local energy demand. This impact on the said areas is positive and represents an important opportunity. The unit of measure for this criterion should be the percentage of the total production used to satisfy local energy demand or the percentage of the local energy demand satisfied by the plant.

LENGTH OF OVERHEAD TRANSMISSION LINES

It is measured in kilometres or meters and it generally represents an environmental cost, because of the negative impact described in the previous chapter. Nevertheless, in remote mountain areas the construction of a transmission line could represent a benefit for future development.

LENGTH OF NEW ACCESS ROAD TO THE PLANT

As for this impact the same considerations made for the transmission lines can be repeated.

5.3 BACKWATER AREA

The backwater area can be defined as the upstream area influenced by the presence of a dam or weir or any other diversion works.

BACKWATER VELOCITY (MEAN VALUE IN THE MIDDLE OF REACH IN CASE OF MEAN WATER)

The velocity of water is one of the abiotic parameters which influence biotic indexes. The choice of abiotic parameters only to describe the environment in the present environmental impact assessment is due to the fact that abiotic indexes are much easier to be measured than biotic ones and they nevertheless give an account of the impact on the environment of an action. In the software for backwater velocity the average value in case of average flow rate has been chosen because it is supposed that it can describe the influence of diversion works as well as possible. This is an absolute parameter measured in m/s. As it is not referred to a situation without works realised, it's mainly interesting as a global indicator of the effect of works when different design alternatives are compared. The lower the velocity is the higher the negative impact of the plant on the environment is.

BACKWATER LENGTH IN CASE OF MEAN WATER

This is another absolute parameter to determine the effect of the diversion works on the river. Usually, the higher the works are with respect to the bottom of the river the longer the backwater length and the negative impact are, because the modification of the environment caused by the plant is higher. That's why, especially in mountain scheme, Tyroelan intakes or some other similar diversion works, which don't cause appreciable backwater effects, should be generally preferred.

LENGTH OF RIPRAPS OR LEVEES IN THE BACKWATER AREA

This impact can be measured in meters or kilometres. In the default set of parameters proposed in the software it's considered as an action with positive impact, because of the increase in safety of the surrounding districts. It can be seen even as a negative impact or both negative and positive, depending on the particular situation.

TOTAL NEWLY INUNDATED AREA/ORIGINAL RIVERBED AREA

This is the first parameter comparing the new situation with the original one: that's why it's measured by a percentage. It's generally considered an environmental cost because of the loss in areas within an environment particularly sensitive as the riverine one.

LENGTH OF IMPERVIOUS EMBANKMENTS OR LEVEES

It can be measured in metres or kilometres. It is a negative impact because of the potential modification induced in surface and groundwater water regime from and to the river.

PERCENTAGE INCREASE IN LOW WATER RIVERBED WIDTH

This is considered a positive impact. In some particular situations, among the completion works of a plant a rearrangement of the low water riverbed is included. An increase in the width can contribute to decrease low water velocities and improve the possibilities of the thalweg ecosystem quality. It must be said that it is not a very important impact indeed.

AREA OF NEWLY CREATED EMBANKMENT VEGETATION

This is considered a positive impact, too. Where new embankments would be realised, an important mitigation measure consists in providing an adequate vegetation covering. In many situations this newly created embankment vegetation contribute to improve the quality of the environment in the vicinities of the diversion works.

CREATION OF SLOW VELOCITY OR SHALLOW WATER AREAS

The presence of diversion works can represent even a source of positive impacts and this is one of them. The creation of slow velocity / shallow water areas can be either caused by the works themselves or newly realised on purpose as a mitigation measure. These areas have an important environmental role because they may become sites for valuable riverine ecosystems. Their creation can represent a source of improvement of environmental quality in rivers already deteriorated by human action.

DEPTH IN THE MIDDLE OF THE BACKWATER AREA/UNIMPOUNDED DEPTH

This impact belongs to that set of abiotic and rather easily measurable parameters chosen to take into account biotic effects surely existing, but hardly or in long terms measurable. In the default list this is considered a positive impact, but in some situations, as we said in chapter 4 a negative impact could be connected with it.

TOTAL LENGTH OF BACKWATER/MAXIMUM WIDTH OF BACKWATER

This is the last parameter used to define the impacts in the backwater area. The ratio between the total length of backwater and the maximum width of backwater is an intensive parameter giving an idea of the extension of the backwater in connection with the importance of the river. The value of the parameter can vary from zero, in case of diversion works which don't created any backwater effect, to very high values 100 and more, in case of high dams in narrow rivers. Even in this case the impact can be negative or positive depending on the specific situation.

5.4 MULTIPURPOSE EFFECTS

In this paragraph we deal with the impacts connected to a small hydropower plant within a multipurpose scheme. In the last years an increasing attention has been paid to multipurpose schemes: it became a keyword in many Community's programmes. Obviously all the actions connected to a small hydropower plant inside a multipurpose scheme cause only positive impacts.

RECREATION

It is measured in percentage of the total average flow rate or annual water volume devoted to recreation aims. For example. in some pondage plants the water level in the basin must be kept higher than a prefixed value to allow angling or other recreation activities, so that only a part of the water volume available can be stored for hydroelectric purposes

FLOOD PROTECTION (INCREASE IN FLOOD RETURN PERIOD WITH RESPECT TO THE NATURAL SITUATION)

This positive impact is measured in years and can be very important in some situations. In many small hydropower plants the river banks near to the diversion works must be rearranged and increased in ground level. This action results in an increase of the water level and consequently of the flow rate which the river can convey during floods, that is the return period of the flood with which risks of inundation are connected is increased. Another way to get flood protection is the use of the basin to store a part of the water volume during floods, but the available volume in small hydropower plants is usually very small compared with the necessity of flood protection.

SETTLEMENT

This impact is measured in persons settled thanks to the presence of the small hydropower plant. As we said, the realisation, but mainly the operation, of a small hydropower plant can represent an important opportunity in depressed areas, typically remote mountain or rural areas. So, the number of persons settled is a way to measure the positive impact on environment and society of the plant.

WATER SUPPLY (IRRIGATION, DRINKING)

A lot of small hydropower plants have been realised and are still realised in irrigation network or channels, especially in plains where dozens of low head plants exploit the water resource both for irrigation and energy production purposes, supplying energy for rural electrification or to match electric energy demand for irrigation (pumping stations and so on). In the last decades many small hydropower plants have been realised in drinking water systems, especially in mountain areas, where instead of relief valves small or micro turbines have been installed to exploit head otherwise dissipated. Even in this case an important multipurpose use of water has been achieved and it is worth taking in due consideration. The positive impact is measured in l/s, but it could be even measured in percentage of the total diverted water for hydroelectric scopes used for irrigation or drinking purposes.

CREATION OF ADJOINING ENVIRONMENTAL AREAS

As a mitigation measure to be taken in a small hydropower plant realisation, the creation of adjoining environmental areas is often requested by authorities or on purpose put into effect by the proponent. These areas are different from site to site and it's hard to give general statements on how realise them. Nevertheless they undoubtedly contribute to make the small hydropower plant more easily acceptable from the environmental point of view. The action is measured in square meters of adjoining environmental areas.

CREATION OF AGRICULTURAL AREAS

The realisation of small hydropower plant in remote rural areas can supply energy for land reclamation making available new areas for agriculture. The same goal is achieved in existing irrigation networks where the energy produced can be used, for example, in pumping stations which can supply water to irrigate areas otherwise unwatered.

5.5 WEIR OR DAM

This module deals with the impacts of the weir or dam itself; so you can find here the description of the impacts as regards the diversion works only.

PERCENTAGE OF THE YEARLY WATER VOLUME TRANSFERRED FROM WET TO DRY SEASON

This impact is rare indeed in small hydropower plant, because to transfer any water volume from wet to dry season a very large - and expensive - storage basin is necessary and a small hydropower plant is unlikely to have it. In the default list of criteria this is set as an environmental benefit, but as we said in chapter 4, negative impacts can be connected to this action.

PERCENTAGE OF THE DAILY WATER VOLUME TRANSFERRED FROM NOT PEAK TO PEAK HOURS

This situation is much more likely to occur than the previous one. To transfer water from not peak to peak hours a small basin is necessary - few thousands of cubic meters or less, depending on the peak and not peak flow rate and the duration of peak and not peak period - so that even in a small hydropower plant it can be suitable to realise it. This is considered a positive impact because the transfer allows to produce energy in periods of high demand and consequently reduce the same production with fossil fuels. But, for the same reasons cited for the previous action, even negative impacts - however considered by other actions - can be connected with the present one.

HEIGHT OF GATES AND ANCILLARIES OVER THE CREST OF DAM AND WEIR

A lot of dams and weirs to divert water in small hydropower plants are composed by both fixed and moveable parts. Typically, flap, sector, slide or fixed wheels gates or inflatable dams are installed on the crest of the dam or weir to discharge flow rates during floods or to control water level and so on. Moreover at the intake rakes and trash rack cleaners are usually installed. All this works can have a remarkable visual impact - as counterbalanced gates - to be taken into account. This impact is usually measured in meters over the crest of dam and must be considered together with the following impact.

HEIGHT OF THE FIXED PART OF DAM AND WEIR

The impact of this action is generally negative both for the visual impact and the major risk of artificial flood in case of dam break and failure (the water volume stored by an high dam is greater than small one). This criterion is chosen in many countries as one of the most important in environmental impact assessments. The subdivision of the total height of the dam or weir between fixed and moveable part could be taken as an interesting parameter; in any case the last two parameters must be considered together to assess the impact of the works correctly.

INTERRUPTION OF BEDLOAD TRANSPORT

Most of dams or weirs cause a modification or an interruption of the bedload transport. Tyroelan or bottom intakes are the only ones which don't interfere remarkably on the bedload, so they are to be preferred from this point of view. It must be said that as a matter of fact most of dams and weirs mainly modify the time scale of transport and not the quantity. Dams and weirs, in fact, are usually equipped with flushing gates which every now and then are open to remove material deposited upstream of the diversion works, so that the global quantity of bedload material is not modified. Nevertheless even this time modification generally imply a negative impact on the riparian ecosystem. There are even some cases when the interruption and removal of the bedload material can have positive impact on the river: it's the case of the rivers with very high bedload transport which cause very quick increase in the riverbed elevation and increase the risk of inundation in case of flood.

INTERRUPTION OF RIVER CONTINUUM, INVERSE TO QUALITY OF FISH BYPASS SYSTEM

River continuum means ecological acceptability concerning fish but also benthic organism. A concrete weir, for example 3 m high, usually interrupts it completely. A very smooth ramp (1:10 - 1:15) made of riprap means almost no interruption. In between there is a wide range of solutions, valuable by biologists. For example if the weir interrupts completely the river continuum but a perfect fish bypass system is realised, it compensates the negative impact of the weir. The unit of measure chosen, percentage of interruption, may be no more than an estimation on quantity and quality. Quantity restriction can be due to the size of a system; quality restriction may be caused by a "wrong" system being selective to some kind of fish.

5.6 POWERHOUSE

This module deals with the impact caused by the powerhouse and by its vicinities.

AREA USED BY POWERHOUSE

This impact is usually measured in square meters and it is considered a negative impact, because of the visual impact of the building, the possible fall in value of the neighbouring areas and so on.

AREA USED BY ADDITIONAL CONSTRUCTIONS (ROADS, YARDS)

This impact is usually measured in square meters, too. In the default list of parameters this impact is considered as positive, but we have often said that there are some situations (particularly sensitive areas, natural parks) where every artificiality must be avoided: in this case this impact is certainly negative.

NOISE EMISSIONS FROM POWERHOUSE

The unit of measure chosen for this negative impact is the dBA. This impact is particularly remarkable at powerhouse with turbines equipped with speed increasers or with high rotation speeds (1.500 rpm). In any case this negative impact can be hardly reduced both by an appropriate turbine and speed increasers design and by a suitable project of the powerhouse. On the other hand, it's generally very expensive to reduce noise emissions from powerhouse once it's realised and the hydroelectric unit is in operation.

PERCENTAGE OF UNDERGROUND POWERHOUSE

Because of its visual impact, the interment of the powerhouse must be considered as source of positive impact on the environment. That's why this parameter has been included in the default list of criteria for environmental impact assessment. In some countries this percentage is considered a criterion with high weight in the assessment.

5.7 DIVERSION SECTION

This module deals with the impacts in the river stretch between diversion works and the end of the tailrace channel (restitution of diverted water to the river): this is the area usually more affected by the small hydropower plant.

DIVERSION LENGTH

In some countries this length has the highest weight of all the impacts, negative and positive, in the environmental impact assessment. The impacts of the diversion are in fact concentrated in this section. That's why in almost all the countries a residual flow must be released by the diversion works to mitigate the negative impacts on the diversion section connected to the small hydropower plant realisation.

WETTED WIDTH / WIDTH OF RIVERBED IN CASE OF RESERVED FLOW

This parameter is one of the abiotic indexes rather easily measurable, even in a preliminary design stage, to take into account variation on biotic indexes. The ratio can give an idea of the stress caused in riverine ecosystem by the small hydropower plant realisation. The ratio should be calculated just downstream of the diversion works so that any effect of tributaries or of other diversions is not taken into account.

STRUCTURAL IMPROVED REACH

The percentage of diversion section whose structure has been improved with the realisation of the small hydropower plant can be considered a positive impact because of the major stability achieved and consequently the highest safety of the surrounding districts. This measure is not always essential for the plant, but it's often suitable to improve even the plant operation or it's required from authorities as mitigation or completion works.

On the other hand, if the diversion section has been regulated into a trapezoid you will have problems in finding a suitable as well as an acceptable amount of residual flow. You will never get a perfect result. To reduce residual flow in the diversion section you can improve the structure by means of modification of the breadth of the river bed, depth, roughness.

EFFECT OF TRIBUTARIES

In mountain high head schemes, but even in low head too, the length of the diversion section can be very great and one of the most common charges levelled to small hydropower plants is that "they dry up the river". Apart from the fact that reserved flow must be guaranteed in almost all the countries, so that the river is never completely dried up, the effects of eventual tributaries along the diversion section are often forgotten. So this parameter has been included in the list of the remarkable ones to take into account the important contribution they give to reduce the negative impact on the areas downstream of the water diversion works. The unit of measure proposed is l/s, but even a percentage of the diverted water can be used.

NUMBER OF WASTEWATER DISCHARGING WITHIN THE DIVERSION SECTION

Sometimes it could happen that within the diversion section a number of wastewater channels discharge into the river. The reduction of the water in the river caused by the hydroelectric diversion can make the pollutants concentration in the water increase with environmental problems for the riverine life as well as for human health. So the impact of a small hydropower plant in such a situation increases. This impact can be reduced by reserved flow increasing up to a value high enough to get a suitable dilution of wastewater pollutants even in low flow periods.

RESERVED FLOW

In many countries reserved flow is regulated by a national law that usually only set up a minimum value, but still permits local communities to impose higher values and sometimes unreasonably higher values.

The determination of the reserved flow can be critical for the development of a small hydropower site because too large a residual flow can make an otherwise good project economically unfeasible.

In this guide we don't intend to closely describe the different methodologies in force to determine reserved flow, because this aim is out of the scope of the guide. We mention only that all the dominant methods can be classified in two groups:

- Hydrological methods based on an analysis of the historic time-series and resumed in easy applicable empirical formulae.
- Hydro-biologic methods based in scientific criteria, applicable only to a particular river, and taking into account both hydrologic and biologic parameters.

The former ones are simple and user friendly, but they are not supported by a scientific criterion and are consequently rather arbitrary. They may recommend too high minimum flow values for rivers subject to droughts and too low for rivers with moderated low-water marks.

On the other hand, a large majority of the hydro-biologic methodologies are based in the knowledge of the physical structure of the river . For the past two decades the state-of-the-art model for the depiction of the riverine habitat has been the Physical Habitat Simulation Model (PHABSIM), based on one-dimensional hydraulic modelling and requiring an abundance of empirical calibration data and the collection of these data along the transverse sections of the river. PHABISM is expensive and often non transferable to other streams.

Anyway, the reserved flow represents an environmental benefit for the river. It avoids complete droughts in the river and it's defined as the flow which allow the survival of the riverine and riparian life.

As a matter of fact it represents the most important mitigation measure of a small hydropower plant.

SPECIFIC RESERVED FLOW

As all the specific criteria, specific reserved flow is particularly important. It is usually measured in litres per second and per meter of width of the river bed. Differently from the catchment related value ($l/s/km^2$) it is a morphological and not a hydrological parameter. Usual limits are 30 to 40 l/s/m. The criteria leading to the formula are minimum depth of 10 cm and minimum velocity of 0,3 to 0,4 m/s.

As many other criteria utilised and proposed in the predefined list of the software, this is an abiotic index rather easy to be measured and which can give information about the riverine life conditions similar to biotic indexes.

5.8 HEADRACE CHANNEL/PENSTOCK

PERCENTAGE OF UNDERGROUND CHANNEL OR PENSTOCK

The interment of the headrace channel or of the penstock represents an important environmental benefit because it reduces the plant visual impact and it doesn't introduce any constraint and hindrance in the use of land.

On the other hand underground waterways can have negative impacts too, because a water leakage is more difficult to be detected and for this reason it's more dangerous, especially along steep slopes subject to major landslide risks.

Moreover an underground penstock or channel isn't easily accessible and it's more difficult to carry on maintenance. It's true that modern pipe and channels technologies allow the almost complete elimination of the maintenance so that the environmental benefit of the interment is generally higher than the cost due to hydrogeological risk and to possible major difficulty in operation.

PERCENTAGE OF EARTH CHANNELS

In case of underground channels would not be feasible, earth channels should be generally preferred, because they introduce a less artificial element in the landscape with respect to concrete channels. By the other hand, to convey the same flow rate they require larger wetted areas, so that the land occupied by the canal is larger than with concrete solutions. In the predefined list of criteria the percentage of earth channel is set as a benefit, but the actual statement depends on the single environmental situation.

PERCENTAGE OF ECOLOGICAL FUNCTION

Although diversion channels are artificial they may serve as a biotope corresponding to a couple of parameters. The better the similarity to natural rivers is the higher the ecological function is. It will be difficult to reach 100 % but if you imagine old channels you will see the difference from a new, straight, rectangle concrete channel. Again the percentage is an estimation considering some abiotic facts.

PERCENTAGE OF STRUCTURED EMBANKMENT

This criterion is closely connected with the previous one focusing on the embankment including the semi-aquatic region and vegetation. The same comments made there can be repeated about this criterion.

PERCENTAGE OF CONCRETE CHANNELS

This criterion is dual to percentage of earth channels and can be used both together and in alternative to it. From a bare hydraulic point of view concrete channels should be preferred because on the same hydraulic radius they allow the conveyance of larger flow rates than earth channels. Especially in high mountain schemes, in case of the impossibility of utilising interred pipes as headraces, the choice of concrete channels is obliged. As we said, concrete channels introduce in the landscape a more artificial element than earth channels, but they have less problems with reference to water leakage and landslide triggering risks, even if a lot of sidehill concrete canals interred on rather unstable slopes, a usual solution in old existing plants, washed out.

In conclusion in the predefined list of criteria this is set as an environmental benefit, but single situations must be closely examined about this criterion.

5.9 TAILRACE CHANNEL

Environmental problems connected to tailraces are the same as headrace channels, so the predefined list of criteria proposed in this guide and in the enclosed software are the same too and you can refer to chapter 5.8 for the detailed description.

5.10 TAILWATER AREA

TAILWATER VELOCITY REDUCTION

The unit of measure for this criterion is the ratio between the velocity of water in the original situation and the velocity of water after the plant realisation. The reasons of the reduction can be different: typical is the case of tailwater areas structured to reduce tail water level and increase head in low head schemes. This criterion can be regarded as an environmental cost because of the modification of the natural riverine regime. It must be said that the tailwater velocity reduction is usually not very high, so that the stress induced in the environment is low and temporary up to a new stationary state acquirement.

TAILWATER SURFACE REDUCTION

This criterion is strictly connected to the previous one and it has a water depth as unit of measure. As we have already said, sometimes the river bottom downstream of the powerhouse is lowered to increase head and the tailwater surface elevation can be consequently reduced.

Even for this criterion the same comments made for the previous one can be repeated.

PERCENTAGE INCREASE IN MAXIMUM FLOOD OR DAM BREAK FLOW RATE OR TAILWATER LEVEL

The construction of a dam or of a weir modifies the normal water regime but even the flood too. In particular, in case of dam or weir break a sudden water wave is created: this wave is very dangerous because usually the peak water level is very much higher and faster than in normal flood events.

If the diversion section was short, the initial water level wave wouldn't practically be damped and the percentage increase in maximum flood or dam break flow rate or tailwater level would be very high with possible heavy consequences for the districts around.

PERCENTAGE DECREASE IN LOW WATER RIVERBED WIDTH

This criterion is one of the abiotic indexes used to measure the effects of the small hydropower plants on biotic elements. It has the scope to take into account the benefit caused by a specific mitigation and compensation measure highly recommended, that is the creation of a low water riverbed which guarantees a certain velocity and depth of water even in case of reserved flow, in order to reduce the stress induced in the ecosystem by the reduction of the available water.

It must be said that especially high mountain torrents have flow rates highly variable during the year and the range of water depths and velocities is naturally very wide, so that the biomes living in the rivers are generally adapted to great variations in these parameters: consequently, the weight to be given to this criterion shouldn't be very high for torrents and vice versa can be significant for rivers in plains where the creation of a specific low water river bed can give important benefits from the environmental standpoint.

PERCENTAGE INCREASE IN DEPTH

This parameter is similar to the previous one and it can be used instead of it to take into account the benefit induced by mitigation or compensation measures taken on riverine environment to reduce the impact caused by the plant realisation, with special reference to measures like modifications of riverbed devised to increase water depth in case of reserved flow.

REDUCED SLOPE/ORIGINAL SLOPE

As the last two parameters, this one is an abiotic index, very easily measurable which gives an account of the benefits on biotic parameters caused by a riverbed re-modelling. An increase in water depth is in fact connected to a reduction in slope of a river stretch downstream of the powerhouse. This measure is sometimes adopted to increase head at low head plants in plain or to recover the original head of the plant progressively reduced by sediment accumulation downstream of the powerhouse. The measure gets a double advantage, technical and economical because of the increase in head and energy production, environmental because of the increase in depth even in low water.

6 TECHNOLOGIES SUITABLE TO REDUCE THE NEGATIVE IMPACTS

6.1 FOREWORD

In this chapter we deal with the main technologies and general plant layouts suitable to reduce the negative environmental impact caused by a small hydropower plant.

They can be divided in two categories:

- mitigation measures concerning single design elements;
- non structural mitigation measures, that is relevant to the general plant layout.

Both measures are equally important: the latter ones are typical of a preliminary design or of a feasibility study, when the main strategic choices must be taken. The former ones are typical of a more detailed design stage when the single elements of the plant must be examined and designed.

To assess the environmental impact of a plant in the best way both types of measures should be considered at the same time, so that the global frame within which the plant is located would be more clear and detailed. But sometimes in a preliminary design stage all the information about the site, necessary to detail the single design elements, is not available or too expensive to be acquired, so the description of the plant could be too generic and not sufficient to carry on a significant environmental impact assessment.

6.2 MULTIPLE USE OF THE WATER RESOURCES

In the past years the European Commission considered the multiple use of water resources as one of the key words to support small hydro projects, that is a small hydropower plant should be part of a multipurpose scheme to obtain a financial support from European Commission more easily.

It's to say that undoubtedly the energy production from a small hydropower plant is more easily acceptable from an environmental point of view if it's achieved together with other uses of water.

As everybody knows, competition for use of water has always been strong, but especially in the last years it has become even stronger, because other new users compete to use it, with particular reference to an aesthetic and environmental fruition of the water resource.

So, relevant public authorities, which should be deputed to elaborate strategies for water resources exploitation, obviously prefer a multipurpose scheme allowing the best compromise among different public interests (including in public interests even every production from renewable energy sources carried out by private investors).

Therefore it's strongly recommended, whenever it's possible and applicable, to foresee in the preliminary design stage or even in the general layout of the plant (in any case in the phase in which strategic choices must be taken) a multiple use of water connected with the small hydropower plant realisation.

In many situations a multipurpose use is easily achieved and a lot of examples are available.

Multipurpose schemes can be divided in two main categories:

- Schemes where the small hydropower plant is an ancillary part and the energy production is not the main scope of the use of water.
- Schemes where the small hydropower plant is the main part and scope of the use of water and the other purposes are secondary and mainly achieved to optimise water exploitation.

Now we have a short walk into these two categories.

SCHEMES WHERE THE SMALL HYDROPOWER PLANT IS AN ANCILLARY PART AND THE ENERGY PRODUCTION IS NOT THE MAIN SCOPE OF THE USE OF WATER.

1. NEW SMALL HYDROPOWER PLANTS REALISED ALONG EXISTING IRRIGATION SCHEMES.

   This situation often occurs in plains (e.g. Northern Italy) where hundreds of small hydropower plants have been realised since the beginning of the XXth century to exploit water heads artificially created during the century-made work of man to avoid the erosion of ground due to water during irrigation and to obtain ground slopes suited to food irriga-

tion and consequently to concentrate in single points the difference in head created by these arrangements.
The realisation of small hydropower plants along existing irrigation schemes in plains, as well as the achievement of a multiple use of water, allows the achievement of another important aim, especially if the plant is realised by irrigation consortia or agricultural users associations. The energy produced can be directly consumed for other irrigation purposes, e.g. to feed pumping stations or uses connected with agricultural activities, reducing the costs for farmers which in recent years have seen their competitiveness reduced with the EU aids reduction.
Moreover the realisation of a new small hydropower plant has no further significant negative environmental impacts, because the water is already diverted from the rivers for irrigation purposes and the only problems could be connected with the possible visual impact of the powerhouse and its vicinities which can be anyway reduced.

2. NEW SMALL HYDROPOWER PLANTS ALONG DRINKING WATER SUPPLY SYSTEMS

This application is very diffused especially in mountain areas, where the water is often diverted at high altitude and the final users are hundreds of meters below, so that a high water head can be exploited for energy production instead of being dissipated in relief valves. As the flow rates are usually very low (some decades of l/s) and the heads not too high, the installed power is not very high, but the application, as for small hydropower plants along irrigation canals, is interesting because has no further significant negative environmental impact and the social return is positive because the energy produced, besides being produced by a renewable energy source, can be used to feed local users (night lighting or other public and private uses) and can consequently improve the electric energy supply conditions for the areas near the plant.

3. NEW SMALL HYDROPOWER PLANTS ALONG WATER COOLING SYSTEMS

This application is very interesting and it's rather recent and unusual. It's typical of thermal plants where large amounts of water (decades of m^3/s) are diverted from rivers to supply water cooling systems of the condensers circuit. Water conveyed in pipes must overpass levees both to feed the circuit and to return in the river: in this second step, the energy of the water stream can be used for electric energy production by means of small hydroelectric turbines. The installed power has an order of magnitude enough to supply auxiliary services of the thermal plant (some hundreds of kilowatts). This application can be an important compensation measure of the thermal plant realisation. An interesting example of it is the small hydropower plant realised at Ostiglia thermal plant (1.320 MW) in Italy where a gross head varying from 4,5 m to 7,5 m and a flow rate of 32 m^3/s are exploited by four submerged units to produce 8 GWh/year

4. NEW SMALL HYDROPOWER PLANTS AT SLUICE SYSTEMS

The realisation of a small hydropower plant at a sluice system along large rivers can be an interesting multi-purpose use of existing structures dedicated to other scopes. The exploitation for hydroelectric purposes of the head created by a sluice system allows the production of energy by a renewable energy source without further significant environmental impacts. An interesting and recent example of this application is represented by a pilot project where a so called matrixturbine has been inserted in the stoplog-slot of the ship lock of Freudenau hydro power plant near the city of Vienna.

5. NEW SMALL HYDROPOWER PLANTS AT RAMPS FOR RIVER STABILISATION

This application is rather unusual, but very interesting from the environmental point of view. Especially in mountain torrents ramps for river stabilisation are often realised. The artificial head created by the ramps or by a series of check dams can be exploited for hydroelectric production. It must be said that flow rates and heads are generally low and the installed power too, and the investment couldn't be particularly profitable (payback period very high), but this application represents anyway a chance to get the double purpose of river protection and renewable energy source energy production.

6. NEW SMALL HYDROPOWER PLANTS AT BEDLOAD BARRIERS

About this application we can repeat the comments and considerations made for small hydropower plants at ramps for river stabilisation: bedload barriers create in the watercourse an artificial head usefully exploitable for energy production.

7. SMALL HYDROPOWER PLANTS AT THE TOE OF A DAM REALISED FOR OTHER PURPOSES

   This application is not very usual for small hydropower plants, but diffused for large ones. The size of the plant depends in any case on the flow rates exploited for other purposes (drinking water supply, irrigation, flood protection). As we said elsewhere, the impact of the small hydropower plant is negligible if compared to the impact of the dam, but the production of energy from a renewable energy source is however a source of reduction of the said negative impact.

SCHEMES WHERE THE SMALL HYDROPOWER PLANT IS THE MAIN PART AND SCOPE OF THE USE OF WATER AND THE OTHER PURPOSES ARE SECONDARY AND MAINLY ACHIEVED TO OPTIMISE WATER EXPLOITATION.

1. SMALL HYDROPOWER PLANTS WITH PONDAGE BASIN USED FOR RECREATION SCOPES

   A good mitigation measure applicable to a small hydropower plant is the realisation of a multi-purpose pondage basin. A typical application is to use the basin for recreation scopes as angling and so on: this application requires that the variations of the water level in the basin are not too sudden and wide and it is usually accompanied by the realisation of recreation areas around the basin to complete the multi-purpose scheme.

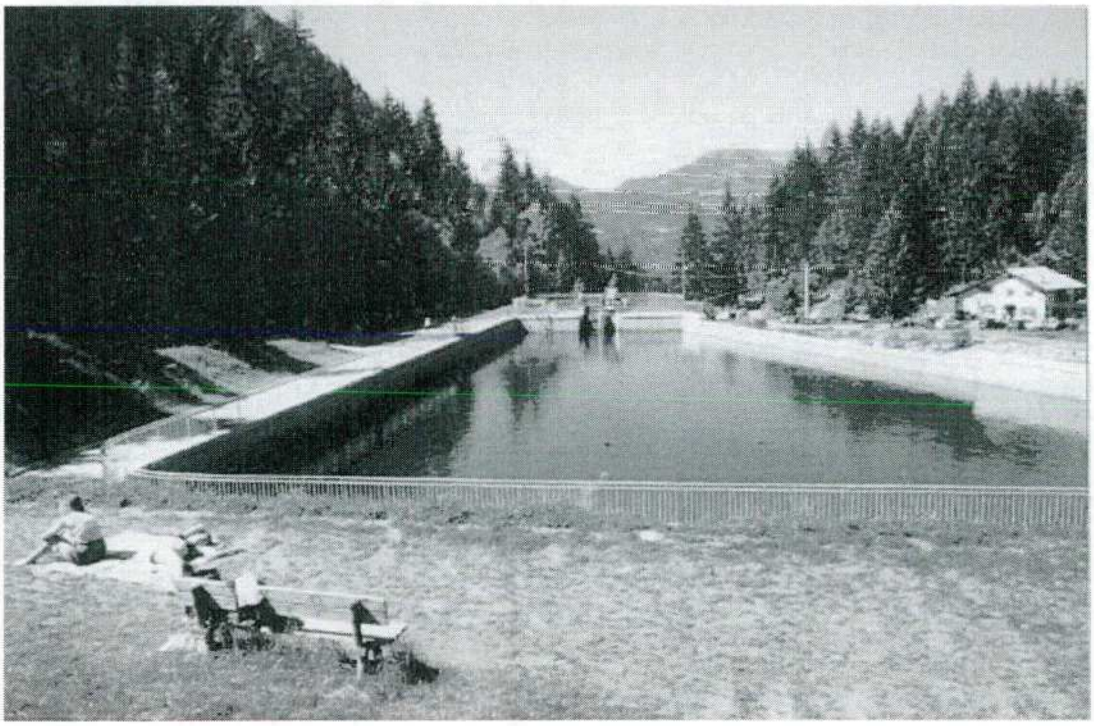
2. SMALL HYDROPOWER PLANTS WITH COMPLEMENTARY FUNCTION OF STABILISATION OF GROUNDWATER LEVEL

   Small hydropower plants equipped with small basins can be used to improve the stability of the groundwater level in area naturally subject to high and undesired variations of ground water level. The presence of a basin with smooth water level variations is surely a source of stabilisation of the water table and of improvement of the environmental acceptability of the plant, because of the optimisation of the use of water.

3. SMALL HYDROPOWER PLANTS WITH COMPLEMENTARY FUNCTION OF INCREASE OF FLOOD PROTECTION

   As we said in chapter 5, in many small hydropower plants the river banks near to the diversion works must be rearranged and increased in ground level. This action results in an increase of the water level and consequently of the flow rate which the river can convey during floods, that is the return period of the flood to which risks of inundation

Figure 6.1: Rino small hydropower plant (Northern Italy): the multi-purpose basin



are connected is increased. Another way to get flood protection is the use of the basin to store a part of the water volume during floods, but the available volume in small hydropower plants is usually very small compared with the necessity of flood protection. Anyway, this complementary function of a small hydropower plant could represent an important card to be played to increase the environmental benefit of the scheme.

4. SMALL HYDROPOWER PLANTS AND WETLAND MANAGEMENT

According to the Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat "wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres".

The realisation of a small hydropower plant sometimes can negatively impact on wetlands or it can be an occasion to mitigate wetland losses in other sites or to improve wetland management around the plant site. This goal can be achieved, for example, creating new wetland areas or restoring existing ones which are very important both for regional and global ecosystems, because, among others, they contribute to improve the quality of water, to recover water tables and they represent a site characterised by a higher degree of biodiversity.

5. SMALL HYDROPOWER PLANTS AND RE-ESTABLISHMENT OF RIVER CONTINUUM

As we said in chapter 5, the realisation of a small hydropower plant can affect the river continuum. Continuum concept stresses that properties of lotic systems vary continuously as stream order increases, that is proceeding from upstream sections to downstream ones. Downstream systems capitalise on materials transported from upstream sources. Downstream and upstream systems are also linked by drift of organisms downstream. Changes in production and habitat are reflected in shifts in adaptations of plants and animals. Besides energy production a small hydropower plant can have the function of re-establishing of river continuum. The possibility of achieving this goal is strictly connected with the devices and works installed and realised at the diversion works, mainly fish passes, but it's even connected with the intake typology itself: a tyroelan intake (bottom or drop intake) should cause a lesser interruption of river continuum in comparison with other typologies (lateral intakes with higher weirs). Anyway, although is perhaps improper to define as multi-purpose a scheme which realise a re-establishment of river continuum, nevertheless it is surely one of its fundamental complementary functions.

Figure 6.2: An invisible Tyrolean intake inside badly restructured embankments

6. SMALL HYDROPOWER PLANTS AND REHABILITATION OF EMBANKMENT

Another additional function of a small hydropower plant can be connected to the rehabilitation of embankments, both from the structural and naturalistic point of view. The presence of a small hydropower plant, especially of its hydraulic works (intake, weirs, and so on) requires a high reliability of the hydraulic system both upstream and downstream of the plant. This reliability is even got by rehabilitation of embankments achievable by bioengineering that is by the combination of biological, mechanical, and ecological concepts to control erosion and stabilise soil through the use of vegetation or a combination of it and construction materials. A rehabilitation undertaken in that way surely restores or improves the situation existing before the small hydropower plant construction.

6.3 FISH PASSES

Fish passes are generally required by relevant authorities at any dam or weir realised in connection to a small hydropower plant. It is often used as device to release reserved flow downstream of the diversion works.

The typology of fish pass to be adopted depends on a lot of factors and an immense bibliography is available about the matter.

Figure 6.3: an excellent example of environment friendly and effective fish pass

Anyway fish passes represent the most important mitigation measure connected to the diversion of water from the river and they are deputed to guarantee the maintenance of river continuum as possible.

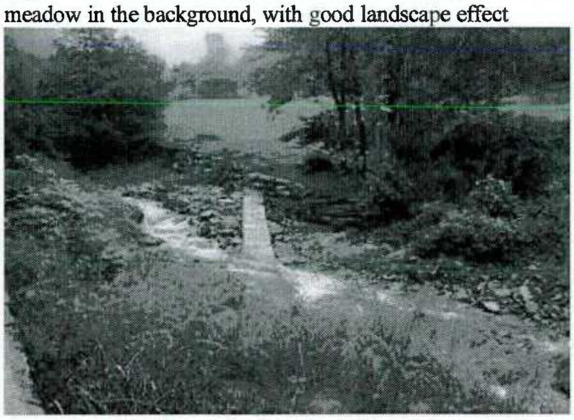
Taking for granted that fish passes are necessary (obviously if fish live in the river stretch subtended by diversion works – it happens that fish passes have been required where no fish live in the rivers), their correct design is fundamental.

As the existing typologies are many, it means that the optimum solution has not been still reached. A particular care must be taken to the maintenance of fish passes, which must be easy in order to guarantee a correct operation. A lot of fish passes, in fact, especially in the past, were completely obstructed by gravel and other materials, making them practically unserviceable.

6.4 PENSTOCK INTERMENT

Penstock interment should be achieved any time it is possible. Pipe and coating technologies have reached a very good reliability level, so that an interred penstock practically requires no maintenance for decades and on the other hand the result on environment but especially on landscape is excellent. In any case a particular care must be taken in sidehill schemes where the landslide risk can be higher for interred penstocks than for outdoor ones, because of the larger zone excavated to install the pipe.

Figure 6.4: An interred penstock crosses the river and the meadow in the background, with good landscape effect



Moreover, to avoid problems however connected to steel pipes corrosion and to eddy currents in the ground and to reduce maintenance, the use of plastic pipes (glass reinforced plastics or HDPE pipes) is advisable.

6.5 UNCOVERED ANCHORING BLOCKS

Figure 6.5: an uncovered anchoring block at 600 mm-diameter penstock without expansion joints.

The impact of an outdoor penstock can be further reduced if the uncovered solution for anchoring blocks is adopted. That means that the penstock is not covered with concrete at anchoring blocks but it's connected to them by steel beams. This solution allows the reduction of the visual impact and the inspection of the whole pipe with higher construction and operation reliability.

6.6 PENSTOCKS WITHOUT EXPANSION JOINTS

Where a penstock can't be interred for any reason, the realisation without expansion joints is preferable because it doesn't require any maintenance and any relevant access tracks or roads to the penstock with the consequent reduction of environmental impact.

6.7 UNDERGROUND POWERHOUSES

Underground powerhouse is a good solution to reduce its visual impact and eventual noise emissions; it must be said that the cost of an underground powerhouse is much higher than an outdoor one and the underground solution can make the investment in a small hydropower plant unprofitable. It's to say that this mitigation measure must be correctly compared with the overall environmental costs and benefits deriving from it, because the area occupied by a powerhouse is generally small (100-200 m^2), and its visual impact is small too.

6.8 BUILDING COATING WITH LOCAL STONE

To favour the fitting of buildings to the environment around, especially in mountain areas, they can be coated with local stone. In this way powerhouse becomes similar to a mountain hut

Figure 6.6: a powerhouse coated with local stone and appearing like a mountain hut.

and diversion works generally have a reduced visual impact. Coating with local stone is often applied even to penstock's saddles and anchoring blocks. Especially for saddles we think that coating increases the visual impact, because the reinforced concrete volume of the saddle is generally low and the penstock hide the saddle with its contour. Coating with stone makes the saddle larger and consequently more easily visible.

6.9 CREATION OF TOURIST INFRASTRUCTURES AT STORAGE BASINS

Storage basins can be easily adapted to the

Figure 6.7: a covered and coated with stone anchoring block at 400 mm- penstock: the impact is high.

creation of tourist infrastructures. Storage basins at small hydropower plants are usually small, few thousands of cubic metres, and they can represent a tourist attraction and consequently an important resource in economically depressed areas as some mountain areas. Storage basins aren't usually a tourist attraction by themselves, but if carefully designed and suitably equipped with tourist infrastructures, they can play a remarkable multi-purpose role. The most usual tourist use of storage basins is for angling: the measures to be taken to adapt the basin to this use are not very expensive, but such a use of water can require some constraints in fluctuation of water levels in the basin which can't be too sudden and frequent. The adjoining areas should be fit out with tables, benches, barbecues, fountains and suitably revegetated maybe with naturalistic tracks where the typical trees and flowers of the area can be seen. However, the measures more suitable to make the vicinities of the basin attractive should be examined case by case.

6.10 ENLARGEMENT OF EXISTING ROADS AND TRACKS TO FAVOUR THE DEVELOPMENT OF LOCAL ECONOMY

This is not properly a technology suitable to reduce the negative impacts, but it can be seen as a complementary measure to make the small hydropower plant realisation more easily acceptable by local people and therefore it can be regarded as a way to reduce the environmental impact, in an extensive sense. Sometimes this measure is explicitly required by local authorities as a quid pro quo to issue the authorisations necessary for plant realisation.

In any case, if the enlargement is made with the due cautiousness and avoiding environmental defacement, it surely represents an important opportunity to favour the development of local economy.

6.11 USE OF LOCAL WORKERS FOR THE PLANT OPERATION

Together with the previous one, this is another way to make the small hydropower plant realisation more easily acceptable by local people. It is generally advisable even because local people surely know the plant site and its boundary conditions better than any other and it can represent an important human resource to be exploited for the best operation of the plant. The use of local people is recommended even for the plant realisation: this measure has positive repercussion on local economy not only for the period of the plant realisation, but even later, because small local enterprises can acquire by means of the plant realisation the particular know-how necessary for small hydro.

6.12 RESTRUCTURING OF REGULATED EMBANKMENT

We repeated many times that the realisation of a small hydropower plant often requires works for the consolidation of the embankments. An important mitigation measure is represented by using bioengineering treatments in a prudent manner while tempering their widespread use with precautions. Precautions consist of properly designing bioengineering projects with enough hardness to prevent both undercutting the streambank toe and erosion of the upper and lower ends (flanking) of the treated project reach. This can be accomplished with one or both of hard toe and flanking protection, e.g., rock riprap, refusals, and deflection of water away from the target reach to be protected through deflection structures, e.g., groins, hard points, and dikes. With both of these methods, appropriate plant species should be used in a manner consistent with their natural habitats, that is, in an effort to emulate natural conditions or processes. This is often done with streambank zones that more or less correspond with microhabitats of native plant species in local stream environments. Where possible, both herbaceous and woody species are used with grass or grass-like plants in the lowermost zone that is planted; shrubby, woody vegetation is used in the middle zone; and, for the most part, larger shrubs and trees are established in the uppermost zone. These zones are respectively called the "splash, bank, and terrace zones.".

6.13 BANKS CONSOLIDATION BY MEANS OF NATURALISTIC ENGINEERING TECHNIQUES

By now the naturalistic engineering techniques have reached a high reliability and they are widely used instead of traditional engineering solutions, especially in highly sensitive areas, for banks consolidation. Recent studies demonstrated that this naturalistic engineering solutions are now competitive even from the economic point of view and therefore they are twice as recommended. There are a lot of techniques and this is not the site to discuss them in detail. We merely cite and briefly describe the most diffused: for this description we referred to the publication of the US Army Corps of Engineers-"Bioengineering for Streambank Erosion Control - Report 1 - Guidelines - available on the web site:
http://www.wes.army.mil/el/wetlands/wlpubs.html

HARD STRUCTURES AND BIOENGINEERING FOR TOE PROTECTION

Bioengineering is often used in combination with hard structures. These hard structures are used to protect the toe of the bank or slopes from undercutting and the flanks from eroding. The larger the stream or stronger the flow, the more probable that hard structures will be incorporated into the bioengineering design model. This is also true when risks become greater, such as when an expensive facility is being threatened. Hard structures such as rock riprap, log/tree revetments, tree butts, and deflection dikes are used to protect toes from being undercut or flanks at the upper and lower ends from being washed out. In these cases, water currents are prevented from undercutting the bank either through direct protection of the lower bank with some hard structure or material or through some kind of deflection structure that deflects the currents off the bank. Deflection structures may be some kind of spur dike, vane, transverse dike, or bend-way weir. In the case of hard toes on the lower bank, plants and engineered materials to hold them in place are positioned above the hard toe. Rock riprap keyed into the bank at both the upper and lower ends of a bioengineering treatment are called refusals and prevent currents from getting behind the structure, called flanking. In the case of a deflection structure, these are usually placed in a series at critical points of scour, and plants with engineered materials are placed in between them to help hold the bank. With the aid of these structures and time, the planted vegetation establishes roots and stems in the bank to hold it together and trap sediment. This sedimentation, in turn, leads to spread of the planted species and colonisation by other opportunistic plants.

The toe zone rarely has vegetation employed in it alone, but when vegetation is employed, it is used in combination with materials that extend below the normal flow of water and above it. The principle is to keep high-velocity currents from undercutting the bank either through armouring the bank or deflecting the currents away from the site of concern. Vegetation can then be used either above the armour or in between and above the deflecting structure.

Stone or rock revetments

Stone or rock revetments in a bioengineering application are used at the toe in the zone below normal water levels and up to where normal water levels occur. Sometimes, the stone is extended above where normal flow levels occur depending on the frequency and duration of flooding above this level. Then, vegetation is placed above it in a bioengineering application.

Rock toes are also used streamward or just below other materials such as hay bales or geotextile rolls. Vegetation in the form of dormant willow poles can be placed above this.

A successful example is represented by a rock roll used on the Rhine River in Dusseldorf, Germany, below an installation of wetland vegetation grown in geotextile mats made from coir. The large rock was wrapped in a polyethylene type of rope mesh and then installed. The rope mesh contains smaller rocks and strengthens the system and is similar to the function of gabions that are discussed below. It should be mentioned that this whole system of rock rolls and geotextile mats with wetland grasses or grass-like plants, such as sedges, were placed in between large rock transverse dikes. The dikes were already there before this treatment was installed and to divert river currents away from the banks. The rock roll (toe protection), the transverse dikes, and the geotextile coir mats, work together to obtain wetland plant establishment and erosion control.

Gabions

Gabions are wire mesh baskets filled with rock and formed as boxes of various dimensions. The wire is either galvanised or covered with a plastic coating to increase durability. Gabions are tied together to become large, flexible, structural units and can be stacked in tiers. They can be installed in the toe zone to prevent undercutting and can be stacked or run as a revetment of gabion mattresses up into the splash and bank zones. They can be used in conjunction with vegetation in several ways. Often times, live, willow whips are placed in between the tiers of boxes back into soil that facilitates sprouting. When they are used as a gabion revetment and rock toe, vegetation can be placed in the splash and bank zones above them. Gabions should be used with caution in streams that have high bed-load movement with cobbles and gravel that may break the wire mesh. Also, they are susceptible to vandalism and to undercutting/overturning. If used in a stacked fashion, a geo-technical engineer should be consulted to determine stability; otherwise, overturning and sliding may be a problem.

Lunkers

LUNKERS is an acronym for "Little Underwater Neighbourhood Keepers Encompassing Rheotactic Salmonids." The LUNKERS is designed to provide overhanging shade and protection for fish while serving to stabilise the toe of a streambank. They were first used by the Wisconsin Department of Natural Resources. They are made from treated lumber, untreated oak, or materials made from a combination of plastic and wood. They are constructed by nailing planks to the top and bottom of 15- to 20-cm spacer logs. These planks form stringers, which tie into the streambank at right angles. Planks are nailed to the top and bottom stringer boards and run parallel to the streambank. The entire structure forms a crib, which can be constructed onshore and moved by a loader or backhoe to the installation site. Once in the stream, the LUNKERS is placed in position and anchored by driving 1.5-m lengths of steel-reinforcing rod through predrilled holes in the structures and then into the streambed. These structures are set in a line that simulates the outside bend of a meander. After the structures are in place, the area behind them is filled with rock, which also is used to cover the structure, and then the entire area is covered with soil. Often, the soil is planted with various kinds of vegetation, either woody or herbaceous. Care must be taken to tie the ends into the bank with a transition of rock or into a hard point to prevent flanking.

Bank Crib with Cover Log

Another hard structure placed in the toe zone to stabilise the toe is a "Bank Crib with Cover Log". Like the LUNKERS, it is used to protect unstable streambanks at the toe while at the same time providing excellent over-head cover for fish. The design is a simple crib with abutment logs extending as far back into the bank as necessary to ensure structural stability (1.3 to 1.8 m in stable soils and 3 m or more in unstable soils). The lower abutment logs should be near water level and should extend 45 to 60 cm from the bank. The cover log can then be pinned to the crib log and the lower abutment. The structure can be from one to several logs high, depending upon bank height.

Log revetments

Log revetments are similar to bank cribs with cover logs except these are used to harden the toe and continue up the bank by lining the bank with logs. Then, flood-tolerant plants are placed at the top of and shoreward to the revetment. Depending on the height of the revetment, this may be in the splash, bank, or terrace zones. They are placed with butt ends facing upstream and are overlapped in a shingle fashion. They are secured with cables that are looped around the logs and then are fastened to dead men in the bank. Care must be taken to ensure their longevity by placing rock on both the upstream and downstream ends to prevent flanking of the structure. Rock should also be placed at the toe of the structure to prevent scour.

Root wads

Root wads are live or dead logs with root masses attached. These are also used in the toe zone to protect it from undercutting, but must be used in combination with other materials. The fans of the root wads provide an interlocking wall protecting the streambank from erosion. The voids within and between the root wads are filled with a soil mix and planted with live, willow clumps or root pads. The root wads are laid on top of a keyed-in shelf of stone and support logs. This shelf includes a layer of bottom support logs flush with one another, shingled together, and running parallel to the streambank. The root mass should be a minimum of 1.5 m in diameter and angled slightly upstream towards stream flow. This treatment should be placed at a base elevation that is consistent with water levels during the major part of the growing season. The bottom two-thirds of the root wad should be in water during that period of time. The upstream and downstream ends of the root wad treatment should be tied into hard points made from rock or some natural hard feature so as to prevent flanking.

Deflector dikes

Deflector dikes are any constructed protrusions into the water that deflect the current away from the eroded bank. These consist of transverse dikes, hard points, groins, bendway weirs, and stream barbs. They are usually made of rock, but other materials such as logs or trees can be used. As mentioned above in the Dusseldorf, Germany, example, bioengineering treatments often use vegetation between deflector dikes. The dikes and the bioengineering treatments work as a system to stabilise the streambank. Transverse dikes differ from hard points or groins by projecting further out into the stream. Bendway weirs and stream barbs are low rock sills. Flows passing over them is redirected so that the flow leaving the structure is perpendicular to the centreline of the structure. The structures increased pool habitat availability, overall physical heterogeneity, riparian vegetation, shade, and woody debris density. To design deflector dikes with vegetation, persons are needed with training both in hydraulic engineering and bioengineering working as a team. Hydraulic engineers should be consulted for design, construction, and placement of the deflector dike, and bioengineers or someone with training in botany should be consulted for use and placement of the vegetation.

BRUSH MATTRESS

A brush mattress, sometimes called brush matting or a brush barrier, is a combination of a thick layer (mattress) of interlaced live willow switches or branches and wattling. Both are held in place by wire and stakes. The branches in the mattress are usually about 2 to 3 years old, sometimes older, and 1.5 to 3 m long. Basal ends are usually not more than about 3.5 cm in diameter. They are placed perpendicular to the bank with their basal ends inserted into a trench at the bottom of the slope in the splash zone, just above any toe protection, such as a rock toe. The branches are cut from live willow plants and kept moist until planting.

WATTLING BUNDLES

Wattling is a cigar-shaped bundle of live, shrubby material made from species that root very quickly from the stem, such as willow and some species alder. These bundles are laid over the basal ends of the brush mattress material that was placed in the ditch and staked. Wattling bundles may vary in length, depending on materials available. Bundles taper at the ends; this is achieved by alternately (randomly) placing each stem so that about one-half of the basal ends are at each end of the bundle. When compressed firmly and tied, each bundle is about 15 to 20 cm in diameter in the middle.

BRUSH LAYERING

Brush layering, also called branch layering, or branch packing, is used in the splash zone, but only in association with a hard toe, such as rock riprap, in the toe zone. It can also be used in the bank zone. This is a treatment where live brush that quickly sprouts, such as willow species, are used in trenches. Trenches are dug 0,5-2,0 m into the slope, on contour, sloping downward from the face of the bank 10 to 20 degrees below horizontal. Live branches are placed in the trench with their basal ends pointed inward and no less than 20 cm or more than 50 cm of the tips extending beyond the fill face. Branches should be arranged in a criss-cross fashion. Brush layers should be at least 10 cm thick and should be covered with soil immediately following placement and the soil compacted firmly.

VEGETATIVE GEOGRID

Vegetative geogrid is a system that can be used in the splash zone and actually extend further up the bank, into the bank, and possibly terrace zones. The system is sometimes also referred to as "fabric encapsulated soil." It consists of successive walls of several lifts of fabric reinforcement. In between the lifts are placed 1.5- to 3.0-m-long live willow whips. The design is based on a dual fabric system modelled after synthetic fabric retaining walls used by engineers for road embankments and bridge abutments. Two layers of coconut fibre-based fabric provide both structural strength and resistance to piping of fine material. Piping is that process where internal erosion of soils occur; that is, water seeps in from above through a porous layer of soil, such as sand lenses, and erodes that layer from where it enters to where it exits further down slope. The inner layer is a loose coconut fibre blanket held together by synthetic mesh netting and is used to trap finds and prevent piping. The outer layer is a strong, woven coir fabric to provide structural support. Sometimes, the latter fabric is substituted by even stronger, more durable synthetic materials, that are formed by a matrix of geo-synthetic bands. The disadvantage of the latter materials, however, is that they are not very biodegradable. Of course, vegetation would mask the materials so they are not visible.

DORMANT POST METHOD

This treatment consists of placing in the splash zone and perhaps the lower part of the bank zone, dormant, but living stems of woody species that sprout stems and roots from the stem, such as willow. Willows are normally used and are cut into 3 to 4,5 m posts when the leaves have fallen and the tree is dormant. The dormant posts store root hormones and food reserves (carbohydrates) that promote sprouting of stems and roots during the growing season. Dense stands of 4- to 6-year-old willows make the best harvesting areas.

DORMANT CUTTINGS

Dormant cuttings, sometimes called "live stakes," involve the insertion and tamping of live, rootable cuttings into the ground or sometimes geotextile substrate. In higher velocity streams, such as over 1,6 m/s, this method usually is applied in the splash zone with a combination of other methods, such as the brush mattress and root wad methods. Dormant cuttings can be used as live stakes in the brush mattress and wattling as opposed to or in combination with the wedge-shaped construction stakes previously mentioned. They can also be placed adjacent to the brush mattress. They can also be used in the matrix openings of the root wad logs along with root pads of other vegetative materials. If cuttings are used alone in the splash zone, the toe should be very stable and velocities should be less than 1,6 m/s. Also, the soil in which they are placed should be fairly cohesive.

ROOT PADS

Root pads are clumps of shrubbery composed of such species as willow (shrubby forms), alder and others. They are often used in the splash zone as a part of root wads where the root pads are positioned in between them. Root pads can also be used further up the slope into the bank and terrace zones. Caution should be exercised in planting these during the dormant season. They can be removed from harvest areas and placed at the project site with front-end loaders. "Veimeer" type spades are sometimes used on root pads where species have deep penetrating roots, whereas front-end loaders are used on species whose roots spread out more at the surface. Placement of root pads on slopes greater than 1V:6H should include securing the root pads by driving 5 cm.-diam, 50 to 80 cm-long wooden stakes through the pads at 0,50 - to 1,0 m intervals.

BIOENGINEERING TECHNIQUES IN THE TERRACE ZONE

The terrace zone, as mentioned earlier, is rarely flooded and usually not subjected to erosive action of the stream except during occasional flooding. When flooded, it receives overbank flooding with return flows that can cause gulling and rilling to occur on the fall of the hydrograph. It is in this zone that vegetation is needed with deeply penetrating roots to hold the bank together, such as larger flood-tolerant trees. Grasses, other herbs, and shrubs can be planted in between the trees, depending on their shade tolerance. Bioengineering, per se, is not normally used in this zone unless there are deep gullies that have occurred as a result of return flows or slopes still occur in this zone that are 3H:1V or greater. In these cases, brush layering or contour wattling treatments are often employed across the gully or on the contours of the slope. Care should be taken in using large trees in this zone. They should be planted far enough back from the bank that their shade does not kill out the vegetation in the splash and bank zones. Narrow channels, especially, can be completely shaded from one side.

Hydroseeding and hydromulching can be a useful and effective means of direct seeding in the terrace zone, particularly on slopes greater than 3H:1V and places where it is difficult to get equipment. Sometimes, it is possible to work from a small barge and use hydroseeding and hydro-mulching equipment on the barge and blow them onto the bank.

6.14 SLOPES CONSOLIDATION BY MEANS OF NATURALISTIC ENGINEERING TECHNIQUES

A lot of techniques used for bank stabilisation can be used for slopes consolidation, too, but latter one is much more "vegetation oriented", so they're worth to be mentioned separately from former one, even if the two methodologies go hand in hand.

According to Schiechtl four construction typologies can be individuated within the bioengineering techniques:

COATING INTERVENTIONS

By their action on the whole surface, coating interventions quickly protect the soil from surface erosion and from sun irradiation.

The most common methods for coating are:

- Sodding
- Grass seeding
- Woody species plantation
- Meshes for erosion control
- Sown mattresses
- Concrete grids filled with soil and vegetation
- Diffused vegetation cover

STABILISING INTERVENTIONS

Stabilising interventions have the scope of reducing up to nullifying mechanical stresses in the soil. They stabilise and consolidate sliding slopes mainly by the root interpenetration. They are usually realised by trees, shrubs and brushwood. These interventions are usually completed with coatings interventions.

The most common methods for stabilising interventions are:

- Cuttings
- Wattle fence
- Fascines
- Fascines drainage
- Drills with live fascines and plants
- Layer of willow cuttings
- Brush layers
- Palisades

COMBINED INTERVENTIONS

Combined interventions consolidate unstable slopes using both live materials (plants or parts of plants) and hard structures (rock, concrete, wood, steel, plastics). In this way a longer life and higher efficiency of the retaining works is achieved.

The most common combined interventions are:

- Vegetated rock walls or ripraps
- Drain wedges
- Vegetated gabions
- Vegetated geomats
- Live crib walls

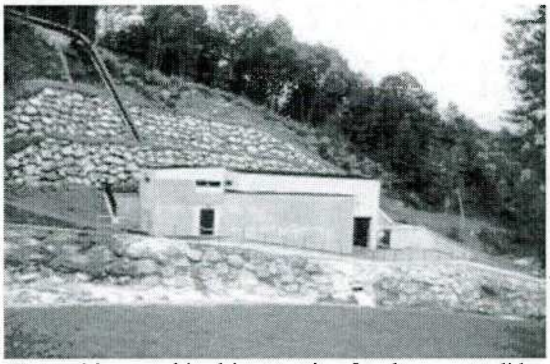


Figure 6.8: a combined intervention for slopes consolidation at a small hydropower plant.

COMPLEMENTARY INTERVENTIONS

Complementary interventions include sowing and plantation in the widest meaning and are used in the final stage of design to complete works even from an aesthetic standpoint.

The most common combined interventions are:

- Plantation on site of species grown in nursery
- Translation on site of autochthonous vegetation grown elsewhere
- Plantation of rootstocks

6.15 CREATION OF LOW WATER RIVER-BED

In many cases, especially where reserved flow is calculated with hydrological methods, the flow downstream of diversion works is very dispersed in the riverbed and the riverine life is subject to significant stress for this reason. The creation of a low water riverbed which guarantees a certain depth of water even in case of reserved flow can be a compensation measure very important to preserve aquatic life and more generically the wetland ecosystem. Obviously the best results are achieved by means of bioengineering techniques which must be anyway applied correctly and with precautions in order to avoid damages to structure created during flood events.

6.16 CREATION OF INUNDATION AREAS

Inundation areas at the vicinities of the plant, preferably at the diversion section can be an interesting mitigation measure which allows the creation of wetlands, so important from the ecological point of view. Obviously the creation of such an area impose very strict constraints from the point of view of the land management, because the whole zone can't be practically used for no other purpose than naturalistic one, so that it's a measure which must be agreed with relevant public authorities. Besides naturalistic scopes the creation of inundated areas can represent a benefit with regard to the flood protection, even if the storage volume of this area should be very large to be significant for this second scope.

6.17 TREE PLANTING AND GRASS SOWING AT THE PLANT VICINITIES

This is a mitigation measure often required by relevant authorities and it's taken either to restore as well as possible the situation existing before the plant realisation or to counterbalance tree cutting during plant construction. Sometimes tree planting is used to completely or partially hide several parts of the plant and reduce the visual impact or to constitute a natural barrier to noise coming from the plant.

In any case it is a mitigation measure with low cost and high environmental benefit and it's therefore strongly recommended.

6.18 PENSTOCKS AND STORAGE BASINS SERVING AS SOURCE FOR FIRE PREVENTING

The realisation of a small hydropower plant can give relevant authorities the opportunity, thanks to the construction of the plant waterways to improve the woodland area fire control in mountain zones by means of suitable small artificial water basins or using penstocks or storage basins to fill choppers tanks in case of woodland fire events. An important multipurpose use of water resource can be achieved with a consequent higher acceptability of the plant from the environmental standpoint.

6.19 EXAMPLES: RINO POWER PLANT

We describe now a success story of a plant realised in a regional natural park: it represents an example to be followed, both for the useful collaboration between project staff and environmental authorities in order to minimise impacts and for the results achieved in terms of successful mitigation measures.

ENVIRONMENTAL CONSTRAINTS IN THE DESIGN PHASE

The original project dated back to 1983 had been made on the basis of a 'classical' concept of the plant, i.e. intake, basin, open channel, high pressure penstock, power station, in order to get the best results from an economic standpoint.

The new project was made thinking that it was necessary to make the plant compatible with the existing natural and anthropical environment, believing that it was impossible, and expensive too, to solve the environmental problems only in the erection phase.

- Intake structures

The intake structures which were already in the first project of the Tyroelan (bottom) type, were the best solution with the least impact on the river morphology and consequently on its hydraulic and on its look. So the problem of visual impact could be left to the erection phase.

An important variation to the project of 1983 was the creation of a fish pass to be used also to guarantee the reserved flow. The type of this fish pass - weirs and pools - was stated together with the technical staff of relevant authorities.

- Basin

Unlike the intake structures, the visual impact of the basin was a relevant problem, because it is situated in an area important from the tourist point of view as it is the starting point to climb Adamello mountains.

The place chosen seemed suitable to the aim: in fact the area near the intake structures was characterised by a smooth slope, just like the river. That has allowed the reduction of the earthwork in an area which is quite delicate

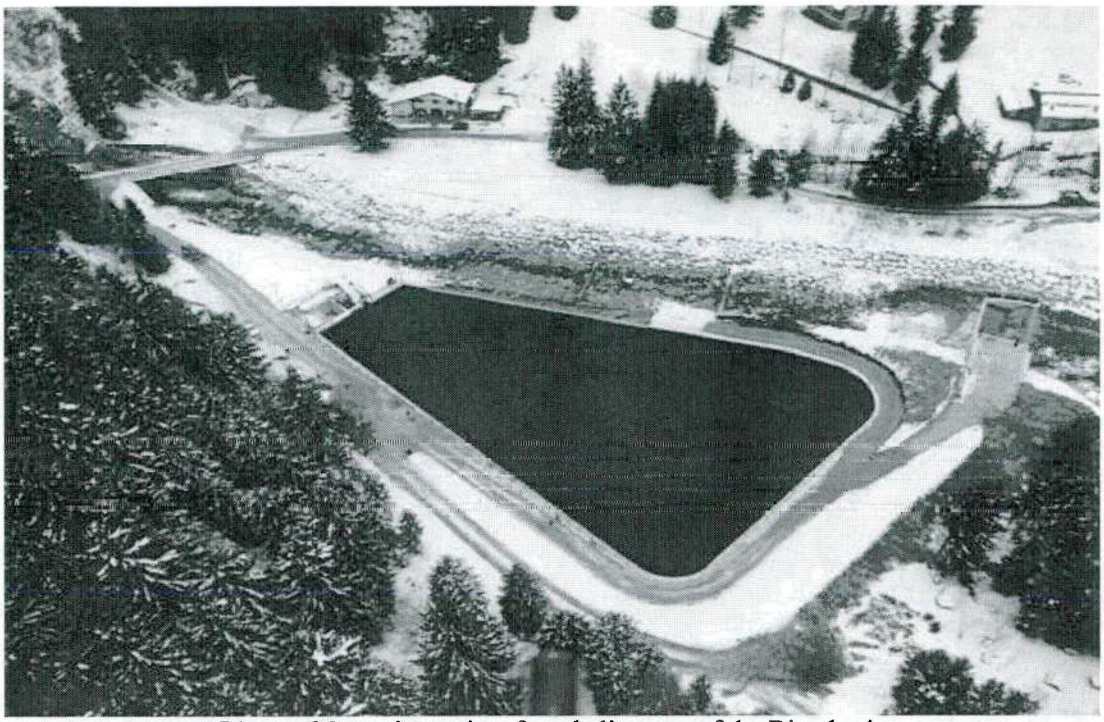


Figure 6.9: a winter view from helicopter of the Rino basin

from the hydro-geological standpoint.

To improve its fitting also in the landscape, the basin was redesigned to follow the irregular lines of the existing environment.
The visible surfaces of the works had to be entirely coated with the local stone reminding the slopes of the river which had been coated with stones after the ruinous flood which in 1987 had hit a great part of North Lombardy.

In any case the basin couldn't but be a relevant modification of the landscape: as we couldn't make it invisible, we thought to transform its presence into something pleasing and useful. In fact there were also some other environmental needs to take into consideration, especially the existing relationship between the river and the human activities there, like agriculture and tourism, the latter continuously improving in the last years.

We tried not only to respect these activities but, when possible, to develop them. That's why the plant was designed to use, in different ways, the excursion of the water level in the basin, which is kept in between precise limits in July and August so that it can be utilised for angling.

The tourist use of the basin has been improved by the construction of a recreation area nearby. For that reason a small wood has been kept near the basin and in it 5 picnic sites have been placed with wood tables, stone barbecues, fountains, a brook with little bridges, a car parking and toilettes block.

People seem to greatly appreciate this area.

- Low pressure penstock

The open channel foreseen in the original project was substituted by an underground penstock at low pressure.

As we were no more obliged to follow a precise altimetric line, we chose a plot that could avoid a fen area of relevant environmental interest. The new plot follows an existing secondary road and so we didn't have to occupy non urbanised areas and we had to cut only a few trees. This fact obliged us to make a part of the penstock in reverse gradient and this fact of course complicated the mechanical aspect. In the lowest part of the reverse gradient, the penstock has been equipped with a flush valve, while in the upper part of the penstock an automatic vent valve had been placed.

The disadvantages of the new designed solution can be summed up as follow:

a) higher construction cost;
b) higher cost in the extraordinary maintenance;
c) emphasising of the transient phenomena due to the long penstock. For that reason the two turbines are equipped with flywheels to synchronise them more easily, even if they work only connected to the national electric grid.

- High pressure penstock

During the design phase we thought to put all the penstock underground. But apart the very high costs, the result, on the environmental impact, was unattractive. The large earthworks required by the digging in are not advisable on very steep slopes, because of their instability. Moreover the erection phase has usually a great impact on the environment. For safety reasons, because of the high pressure, the penstock should be checkable as easily and as soon as possible. That's why we decided to keep open air the part of the penstock at high pressure and to inter the low pressure one.

To attenuate the environmental impact we tried to reduce deforestation and to use materials and colours similar to the natural landscape. We lessened visual impact by using anchoring blocks which don't coat the pipe with concrete which are usually more expensive than the usual ones which cover the pipe with concrete. In these last ones the penstock is completely wrapped in the concrete, while in the first ones the concrete structure stops 50 cm under the penstock and can be usually put underground. To get the best results the upper parts of the blocks have been completely coated with local stone.

Another aspect that was taken into consideration during the design phase was the possibility for men and wild animals to cross the penstock so that it didn't become an obstacle line in the Park. For that reason some parts of the penstock have been raised in order to make underpasses while on the parts close to the ground, small wood and stone bridges have been built.

- Power station and tail race

The original project has been modified in the course of the works also on the basis of the indications of the different institutions involved.

The layout modification which had the worst consequences on the production was the moving of the power station upstream of Rino di Sonico village with a loss in head of about 60 m.

Nevertheless in that way we could return the water to the river upstream of the village giving an answer to the environmental and hygienic needs and also feed a sprinkler irrigation plant.

To this aim an exchange chamber has been realised which allows the conveying of the water from the turbines directly to the river or to the irrigation plant without affecting, in any way, the operation of the hydroelectric plant or of the irrigation one

An auxiliary intake, already existing, can feed the irrigation plant when the hydroelectric plant is not working. But usually the water used comes from the turbines because it is already desilted.

ENVIRONMENTAL CONSTRAINTS IN THE ERECTION PHASE

In the erection phase we took in great consideration the impact of the permanent works, but also the temporary ones, which are usually neglected, have been particularly minded.

- Intake structures

The original project has been modified and the river banks near the intake structures and the basin have been rearranged with stones, among which soil and willow trees have been put. Concrete has been used only for the toe zone.

- Low pressure penstock

During the penstock interment, great care was devoted to the environmental restoration in the zone near to the fen area of relevant environmental interest. The penstock has been placed only for small parts in private grounds and the track has mostly followed the small existing footpath.

For paths restoration, only local materials and traditional technologies have been used, in particular the retaining walls have been made of dry walls.

- High pressure penstock

The open air penstock was the work with the greatest impact because it couldn't be interred in without consequences on the slope stability because of the steepness of the side it had to be placed on.

To reduce also the visual impact we tried to avoid big external works and also deforestation which depends on the way the site erection is made as well as on the maintenance needs.

Just to allow the access also in the future, some permanent facilities are used for the erection, like inclined plans and cableways.

Recently also the helicopter is being used, but it requires the deforestation of a large strip close to the penstock.

At Rino plant we have utilised a temporary rope-way, usually called "Blondin", which requires, as fixed structures only two concrete blocks, one at the top and one at the bottom of the cableway.

Because it was not permanent, the maintenance of the penstock would become hard and expensive.

So we had to think of technical solutions which didn't need frequent maintenance. We have therefore chosen a penstock without expansion joints which involves oversized steel structures.

The anchoring blocks have been made with a flat top and steel support over-structures, saddle shaped, which are quicker to erect, less bulky and less visible.

- Power station and tail race

The power station was moved - as we have already said - upstream of Rino di Sonico village in an area suitable to supply the diverted water to an existing irrigation plant, as it had been required by local authorities.

So the station happened to be in a narrow place, between Remulo river and the steep slope of the mountain.

To reduce the necessity of reshaping the slope, the power station was developed in length and articulated on four floors according to the ground gradient.

As the area was subject to landslide, the slopes have been consolidated using the bioengineering techniques.

6.20 EXAMPLES: PÖLS I AND II SMALL HYDROPOWER PLANTS

River Pöls is located in Styria, Austria, thus in a semi-alpine region with a long tradition in small hydropower plants and a with a high level potential. The plants described are situated side by side. Both are diversion type plants built in 1991 and have the following main technical data:

Plant 1

Catchment area	405 km^2
Rated discharge	7 m^3/s
Net rated head	25,25 m
Power	1520 kW
Length backwater	150 m
Rubber dam	19,0 x 1,7 m
Annual production	9,1 GWh
Pressure pipe	GF-UP
Length	1531,5 m
Diameter	2100 mm
Kaplan Axial-S-Turbine	ϕ 1060 mm, 6 blades, 600 rpm

Plant 2

Catchment area	410 km^2
Rated discharge	7 m^3/s
Net rated head	19,70 m
Power	1100 kW
Length backwater	320 m
Rubber dam	19,0 x 1,9 m
Annual production	7,1 GWh
Pressure pipe	GF-UP
Length	1257,0 m
Diameter	2100 mm
Kaplan Axial-S-Turbine	1060 mm, 6 blades, 600 rpm

Summer/Winter ratio of energy production is 42,58 %.

Within the engineering as well as the imple-

Figure 6.10: an overview of the diversion works at Pöls small hydropower plants

mentation process the success depends on a precise and consequent project management.

To achieve a speedy granting procedure together with an acceptable result, ecological demands and objectives has been met continuously and equally with technical contents. The following features were essential:

- Residual flow
- Fish bypass systems
- Special design work in backwater and tailwater area
- Biological swimming lake

About some of them we report additional comments.

RESIDUAL FLOW

Due to a lot of ecological sound reasons, a rather complex regulation was found. In general a total discharge of 600 l/s was fixed. Part of it (400 l/s) flows through the fish bypass – 200 l/s are passing a regulation device. Between April and September the residual flow is variable as a function of the recent discharge. Curves and functions, describing the relation between discharge and residual flow, are stored in an electronic control device. Decisive input is the performance of the turbine.

600 l/s are roughly 10% of mean flow.

FISH BYPASS SYSTEM

Both systems are so-called by-pass channels with ponds and steps.

The main features are the following:

System 1

- Total head 3,7 m
- Max. head between ponds 0,2 m
- Max. depth in ponds 1,0 m
- Number of ponds 17
- Total length 125 m
- Over all slope 3,0 %

System 2

- Total head 3,1 m
- Max. head between ponds 0,2 m
- Max. depth in ponds 1,0m
- Number of ponds 14
- Total length 125 m
- Overall slope 2,5%

The technical data show that both systems are very similar to natural creeks and therefore offer fish as well as benthic fauna non-selective passing conditions. To achieve a good result it is necessary to put heavy efforts on the realisation phase of such small scaled structures like bypass systems. The final step has to be a hydraulic testing phase likely resulting in a correction of details. All these activities have been carried out and a monitoring phase lasting some years is still going on.

BIOLOGICAL SWIMMING LAKE

Some ten meters away from the power house a so-called biological swimming lake was constructed. In principle it is an artificial lake fed by pumping groundwater. It is self cleaning due to large vegetation zones covering about 30 % of the total area which is about 7000 m² wide. To avoid water losses it is completely sealed by a plastic foil. The maximum depth is 2,6 m. The temperature of the lake can be regulated by using the waste heat from the generator. The maximum temperature allowed in summer is 24 °C. The maximum warming rate is 4 °C.

Due to additional equipment like a bridge, a path round the lake or some wooden seats, the lake is highly accepted by the population especially by children.

A nice idea of the owner of the site was to install a kind of museum in the power house focussing on a great variety of curious pieces he has collected. The house has been painted outside by children.

7 THE EVALUATION OF HYDROPOWER PROJECTS: THE MULTICRITERIA APPROACH

7.1 FOREWORD

Based upon the previous listed set of criteria that can be considered when designing a new hydropower plant solution, it's clear how it is a major task of planners to impose some order on the problematic situations in which they are acting professionally. In order to pursue this goal they must make all kinds of distinctions, classifications, and other judgements. Therefore, it is very essential that they have tools which enable them to perform this task in a responsible way. A very important subset of these tools are the methods and techniques which assist the planner - as objectively as possible - to classify and conveniently arrange the information needed for a choice, in order that the various participants in a planning process (e.g., policy makers) are enabled to make this choice as responsibly as possible. This should be even considering a wide range of different standpoints.

These joint activities will be called an *evaluation procedure*. The word *evaluation* here means the objectifying - real, actual denomination - of a certain situation and the valuation - appraisal, value judgement - of this objectivated situation. Differently from classical cost-benefit analysis procedures that require an *analytical approach*, evaluation procedures typically involve an *appreciative approach.*

The main role of cost-benefit analysis is determined by the fact that economic efficiency had been the main guiding principle of every type of strategic-planning problem for a long time. In fact, this method had been typically used to translate into a common monetary measure the effects of the various evaluation criteria employed. However such an approach presupposed a *one-dimensional* problem, i.e. a system based on a *single utility function* capable of representing the viewpoints of all the decision-makers involved in the process. The monetary methods, when used as stand-alone methods, are subjected to criticisms because: they use notional figures; they either conceal relevant value judgements or else, simply involve unrealistic and sometimes artificial degrees of precision. This especially concerned such aspects as nuisance, nature, environment, safety, aesthetics, and so on. And – basically - conflicting alternatives are finally evaluated and selected based upon monetary and financial aspects only.

Newer evaluation techniques have attempted to overcome the limitations of this one-dimensional approach, which is effectively single-criterion in that its only unit of measure is monetary, and whose ultimate aim is to maximise the margin between revenue and costs.

Thus, several multi-dimensional evaluation methods of the multi-criteria, multi-objective type have been proposed. They have found their most widespread application in the environmental sector, but there are also attempts to implement such methods in many other decision domains, typically involving interactions between the engineering and the environmental sector.

A basic classification scheme of various evaluation methods is shown by **Fig. 7.1.** A first distinction concerns the difference between:

- *ex ante* evaluation: focussing on the part of the planning procedure which concentrates on the preparation of a planning proposal (e.g., a regional or local plan); it has a "forward looking" nature (what could happen with the implementation of this project?);
- *ex post* evaluation: reviewing the past activities and/or situation which followed a particular decision; it has a typical "backward looking" nature (what did happen with the implementation of this project?).

A further distinction concerns the division of *ex ante* evaluation into:

- *a priori* evaluation: when the choice possibilities under consideration are not known explicitly (e.g., if one tries to generate an optimal plan by means of an objective function and constraints, such as an LP method);
- *a posteriori* evaluation: when all the alternatives and their effects are well known at the beginning of the evaluation procedure.

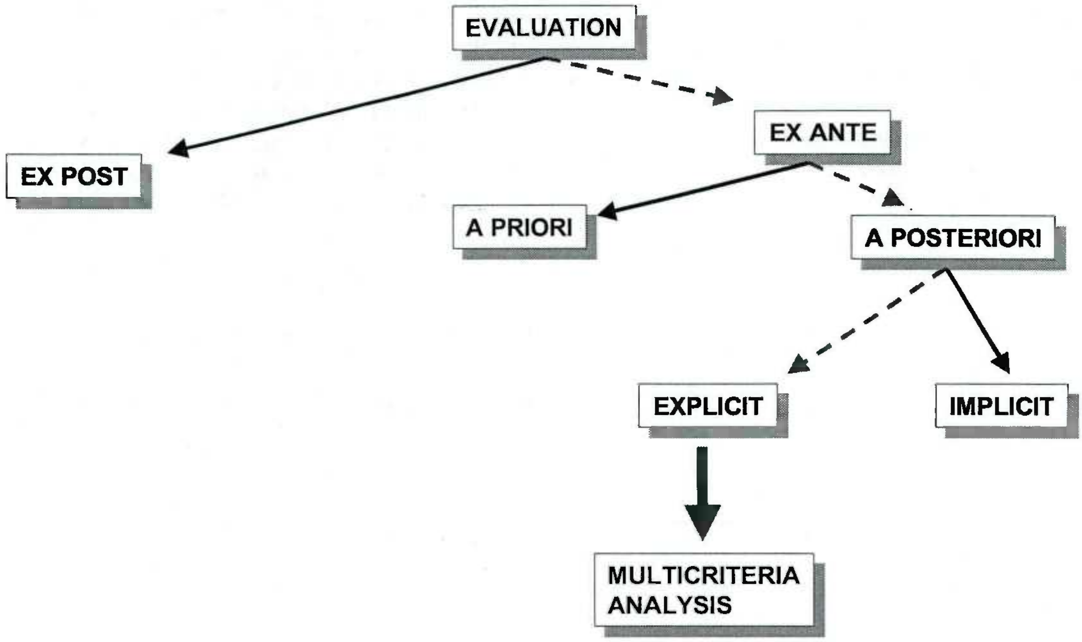


Fig. 7.1 – Classification of evaluation methods (red line is the one here suggested. It leads to consider the multicriteria approach)

A final distinction concerns the division of *a posteriori* evaluation into:

- *implicit* evaluation: an explicit systematic analysis of the choice possibilities is pursued, whereby the activities are focused on the accountability of the final result;
- *explicit* evaluation: it focuses, on the contrary, on the consensus of thought, whereby attention is directed to the participation of - and negotiations between - all parties concerned.

The approach here proposed is the one underlined in Fig. 7.1 It is an ex-ante, a posteriori, and explicit method, typically implemented by a Multicriteria Evaluation Approach (MEA). Cost-benefit analysis can constitute a part of the method. It is not essential even if it is always useful in supplying a framework for a monetary assessment of all the potential projects that are going to be considered.

7.2 THE MULTICRITERIA EVALUATION APPROACH: AN OVERVIEW

MEA'S OBJECTIVES AND BASIC PRINCIPLES

MEA enables the decision maker to investigate a number of different alternatives (projects) in the light of multiple criteria and conflicting priorities. The core of MEA is the construction of the so-called 2-dimensional IMPACT Matrix, where one dimension expresses the various alternatives (say *Projects*) and the other dimension the criteria by which the alternatives must be evaluated.

Thus, it is a *Criteria x Projects* matrix.

Various MEA techniques were developed, depending on the way the information in the matrix is aggregated. The approach here proposed is the goals-achievement method, which include a weighted summation technique where – at least in its initial form – not only numerical weights are attached to the various objectives but also to the groups affected. One of the most essential aspects of MEA is the supply of a method defining the relative importance of one criterion with respect to the other. A common feature of all the MEA techniques is just that they start from a number of explicitly formulated *criteria* (or *standards of judging*). Consequently, they are not measured in one single unit (like cost-benefit analysis) but in a variety of units which reflect as well as possible the nature of the criteria concerned.

A relative weight must be given to each criterion. This weight represents the relative importance (priority) assumed by that criterion within the decision making process. Subjective priorities are then considered entering the relative importance of each criterion into a *Weight-vector* that contains as many values as the criteria are.

Consequently MEA enables the decision-makers to take explicitly into account political priorities within his selection process. This makes the approach pre-eminently suitable to incorporate differences in political viewpoints into an evaluation. The results will then be a *conditional evaluation*, i.e., the outcomes will depend on the political views expressed (*subjective standpoints*).

Thus, generally speaking, MEA provides methods to process simultaneously 2 types of input information: *objective information* (the impact matrix), and *subjective information* (the priority - say the weight - given to each criterion).

It must be stressed the concept that MEA doesn't perform an optimisation method. It simply identifies a set of ranked preferences by assigning *concise scores* to each project. This final score assignment is performed by calculations that take into account both objective and subjective standpoints. The project having the highest score is not the "best". But, more precisely, it is the one that gets the *best compromise* of satisfaction level when all the criteria are simultaneously considered. Obviously this is very evident when many conflicting criteria are used into the matrix.

INPUT AND OUTPUT DATA STRUCTURES

The basic principle of a MEA is then very simple. Firstly, a matrix must be constructed whereby its elements reflect the characteristics of a given set of alternatives which are determined by means of a given set of criteria. An example is given in **Fig. 7.2.** This is the above mentioned *2-dimensional IMPACT Matrix.* In the past several names were proposed for such a matrix besides the one here proposed (project-effect matrix, score matrix, effectiveness matrix). In this study we are going to use indifferently the terms *impact matrix* or *evaluation matrix* if the criterion scores (say effects) have been measured in different units. The term *effectiveness matrix* will be used if the criterion scores have equal units, typically when they are standardised by a normalisation procedure as described here after.

Table. 7.5 shows the evaluation matrix of the case study discussed in this chapter to present a practical MEA application exercise.

To obtain an impression of the quality of the various projects under examination by means of such an evaluation matrix, information is needed about the relative importance attached to the criteria. Sometimes, however, the evaluation matrix itself provides a very clear picture of the general differences between the various alternatives so that no further analysis is needed. For example, this can happen if the evaluation matrix shows that there is indeed one alternative for which the criterion effects are the best for all criteria. This project is in that case *dominant* over all other alternatives, irrespective of the priorities attached to the various criteria. Such a dominance analysis can also be performed beforehand to reduce the number of choices.

Nevertheless, it is not unusual that many conflicting criteria are considered, which make a straightforward interpretation of the evaluation matrix almost impossible. In that case, as already said above, an additional statement is required regarding the importance (say priority) of the various criteria. This is the input information of the subjective part of the problem. When several decision-makers are going to take part into the selection procedure, we have to deal with various views (subjective standpoints) concerning possible criterion priorities. These standpoints can be summarised into a priority matrix, having the structure described in **Fig. 7.3**.

Fig. 7.2 - Structure of an EVALUATION Matrix (named even IMPACT Matrix or EFFECT Matrix)

	ALTERNATIVES (PROJECTS)							
CRITERIA	**A**	**B**	**C**	**D**	**...**	**...**	**...**	**Etc.**
1								
2								
3								
...	*Criterion scores (or Effects, or Impacts)*							
...								
...								
Etc.								

	CRITERIA							
VIEWS	1	2	3	4	...	...	...	Etc:
I								
II								
III								
IV	*Priorities (number or qualitative expressions)*							
...								
...								
Etc.								

Fig. 7.3 - - Structure of a PRIORITY Matrix

The priorities can be represented by means of *quantitative (real) numbers* (e.g., 0.18, 0.02, 0.88), by means of *ordinal expressions* (e.g., "very important", "important", "less important".) or *binary statement* (relevant, irrelevant).

Quantitative expressions are usually referred to as weights, whereas ordinal expressions are designated as priorities. The approach here followed is based upon the use of quantitative numbers, in order to perform sensitivity analyses on subjective standpoints throughout continuous weight-scales. Thus, ordinal and binary statements – if any – must be necessarily transformed into a quantitative scale.

There is a large number of arithmetic techniques to link the information from the evaluation matrix (i.e., Fig. 7.2) with the information contained in the priority matrix (Fig. 7.3). Whatever the technique used, the final results is a preference ranking order usually represented by final scores that provide an appraisal for each project. These results could be arranged into a new matrix having the structure shown in **Fig. 7.4.** Such a matrix provides a sensitivity analysis on the preference order of the projects assessed by the different standpoints included into the priority matrix. The results corresponding to every standpoint are presented in a discrete, independent way.

MEA here described proposes also some *graphic metaphors* to perform sensitivity analyses on priorities following continuous variations on weight values. The method used is an adaptation of a hierarchy analysis and implies a priori classification of all the different criteria into homogeneous groups. In this sense, there are importance-factors that can be expressed throughout a set of homogeneous criteria clustered into different groups. For performing the above mentioned graphic metaphors, 2 or 3 importance-factors only must be assessed. This means to manage 2 or 3 groups of different criteria.

The generation of criteria is an essential step of the formulation of the evaluation problem. It is possible to distinguish two different approaches to arrive at a set of evaluation criteria:

a) the *deductive* approach, that evolves from a number of general (say main) criteria, or characteristics of the evaluation problem at hand; these main criteria could include a large number of more specific and homogeneous factors, each representing, on its hand, a single criterion or a smaller subset of

Fig. 7.4 - - Structure of a APPRAISAL Matrix

	ALTERNATIVES (PROJECTS)							
VIEWS	A	B	C	D	...	...	...	Etc.
I								
II								
III								
IV	*Appraisals (ultimate indexes of preference)*							
...								
...								
...								

evaluation criteria; an example of this may be the conventional territorial planning sectors like *Landscape, Working, Environment, Social interactions, Technical & Economic efficiency* etc.

b) the *inductive* approach, that starts with an inventory of all features of the projects; in addition, these features are grouped and – eventually – aggregated in such a way that a set of homogeneous criteria arises.

Both generation methods are based on the assumption that some sort of hierarchy of criteria can be distinguished. Hierarchy analysis involves the concepts of *specification* and *means-ends*. Specification implies a subdivision of a criterion into one or more lower-level criteria, thus clarifying the intended meaning of the higher-level criterion. These lower-level criteria can also be considered as the means to the end, the end being the higher-level criterion. In other words: by identifying the end to very precise criteria, an hierarchy can be built up to higher levels. In this way, several relationships can be identified and proposed within a so called "objective tree".

Anyhow, from a methodological standpoint it should be stressed that when generating evaluation criteria a consequent deduction or induction approach must not be pursued *per se*. A methodical "top-down" or "bottom-up" derivation of criteria will undoubtedly run the risk of generating more or less "artificial" hierarchical patterns, whereby the form surpasses the content. In MEA practical applications, a combination of both approaches – either simultaneously or sequentially – may overcome this problem. In that case it is better not to stress the importance of systemising the *process* of generating criteria, but to watch carefully and systematically that no *lacunae* exist in the final set of evaluation criteria.

In the case of the evaluation of hydropower plants, the problem is facilitated by the fact that the effects of each solution at hand should be already determined as objectively as possible when designing the executable projects. *A priori* list of default criteria can be always extracted from the original project and proposed as common-key for a comparative evaluation. Thus, the *inductive approach* should be preferred if all the project tasks are carried out following a common methodology that leads to the calculation of the most relevant effects. When performing a MEA exercise, it is important to have the possibility of managing a *flexible calculation tool* able to provide a list of unambiguous criteria among which one can select those that are judged relevant for the particular problem at hand. The tool must even provide a flexible approach in clustering the criteria into homogeneous groups, thus enabling the decision-makers in personalising their own sets of higher-level and lower-level criteria. In addition, the user must be able to specify the relative importance of each lower-level criterion within its own higher-level group, as well as the relative importance among the different higher-level groups directly (whilst maintaining constant the relative weight proportion of each lower-level criterion inside the group it belongs to).

The software package that will be discussed in the next chapter performs MEA calculations according to the above mentioned criteria-functions. It even provides a list of default criteria that can be selected by the user according to his objectives. Criteria can be then clustered into 2 or 3 groups defined by the users. Anyhow, the program proposes *3 default groups of higher-level criteria*:

1. *Economic-related factors*: related to the monetary and financial aspects of each project (such as: energy yearly produced by the plant, specific investment required - □/MW, foreseen time of construction, workers employed during operation, etc.);
2. *Environmental-related factors*: related to the impact that each project is able to induce into the environment in terms of variation of the original and natural living conditions (such as: CO_2 emissions avoided, total area newly inundated, length of overhead transmission lines, area used by additional constructions as roads or parkings, noise emission from powerhouse, etc.);
3. *Technical-related factors*: related to the constructive and management aspects that characterise each project (installed rated power capacity, percentage of the daily water volume transferred from empty to peak hours, percentage of underground powerhouse, fixed dam height).

It is essential to underline that the above groups are only a basic suggestion, as the user can subjectively assigning a criterion to this or that group; for example: some constructive aspects - such as the "fixed dam height" - could be seen also as belonging to the group of the environmental-related factors. New groups can be even proposed according to the general meaning given to the analysis. In general terms, when 2 or 3 groups are going to be considered for performing a sensitivity analysis on the priority (viz., subjective) aspects of the problem, attention should be paid in organising homogeneous groups with a similar number of criteria. On the contrary, the risk could be to assign a too much relevant importance to some items when few criteria are included into a group.

7.3 THE STANDARDISATION OF INPUT DATA

DEFINITIONS

Once the impact matrix has been constructed - and independently on the arithmetic procedures we are going to perform to get the MEA final results - the first problem we have to deal with is that criterion effects are mutually incompatible since most of the measurement units will differ from each other. To make the various criterion effects compatible it is necessary to transform them into one common measurement unit, for example taking care that for each criterion the transformed effects will have a range from 0 to 1.

This kind of transformation is called *standardisation* (or *normalisation*).

As stated before, the standardisation procedure produces an *effectiveness matrix* starting from the criterion effects of an *impact matrix.*

STANDARDISATION FORMULAE

- Types of transformations

Suppose we want to evaluate a finite number of alternative hydropower projects i (i = 1, 2, ..., I) by means of a finite number of criteria j (j = 1, 2, ..., J). For each project, the criterion effects z_{ji} are integrated into an impact matrix **Z** of order J x I with the following structure:

$$(7.1) \qquad \mathbf{Z} = \begin{bmatrix} z_{11} & \text{—} & z_{1i} & \text{—} & z_{1I} \\ | & & | & & | \\ z_{j1} & \text{—} & z_{ji} & \text{—} & z_{jI} \\ | & & | & & | \\ z_{J1} & \text{—} & z_{Ji} & \text{—} & z_{JI} \end{bmatrix}$$

Many standardisation methods are used in MEA, which are often specifications of the following generalised transformation function:

$$(7.2) \qquad r_{ji} = \frac{z_{ji}}{\left(\sum_i z_{ji}^{\alpha}\right)^{\frac{1}{\alpha}}} \qquad (\alpha \geq 0)$$

where α is a *scaling-parameter*, which has to be selected a priori. The size of this scaling parameter determines the influence of the absolute magnitude of the various "raw" z_{ji}- effects (viz., referred to each criterion).

The following types of standardisation, even according to different α-values, can be proposed:

1. Vector normalisation;
2. Linear scale transformation;
3. Min-Max transformation.

Whatever the standardisation type, the result is an effectiveness matrix **R** of order J x I with the following structure:

$$(7.3) \qquad \mathbf{R} = \begin{bmatrix} r_{11} & \text{—} & r_{1i} & \text{—} & r_{1I} \\ | & & | & & | \\ r_{j1} & \text{—} & r_{ji} & \text{—} & r_{jI} \\ | & & | & & | \\ r_{J1} & \text{—} & r_{Ji} & \text{—} & r_{JI} \end{bmatrix}$$

- Vector normalisation

This procedure implies that each row vector of **Z** is divided by its norm, so that a normalised plan impact r_{ji} can be determined as:

$$(7.4) \qquad r_{ji} = \frac{z_{ji}}{\sqrt{\left(\sum_i z_{ji}^2\right)}}$$

Note that the use of this so-called Euclidean norm as standardisation factor is obtained by setting the scaling parameter in Eqn.7.2 as α=2. Alternatively, the scaling factor α=1 could be proposed. In such a case, r_{ji} is found by dividing each z_{ji} by the sum of all z-effects for a particular *j*-criterion. Both the approaches calculates an effectiveness score r_{ji} that will only very seldom receive the value 1. Also the value 0 can only be obtained if the original effect z_{ji} is 0 itself. In general, it can be said that in both cases a skew distribution with emphasis to the lower effects is produced. Eqn.7.4 is more attractive to give an additional relevance to larger numbers: in such a case the resulting range of the r_{ji}-scores will be larger than the one obtainable with the scale parameter α=1 (Table 7.1).

- Linear scale transformations

According to what stated at the previous point, it is clear how the higher the parameter α, the larger the range of the r_{ji}-scores that will be calculated for each criterion-raw. When this aspect must be particularly emphasised, the best standardisation procedure appears to be:

$$(7.5) \qquad r_{ji} = \lim_{\alpha \to \infty} \left\{ \frac{z_{ji}}{\left(\sum_i z_{ji}^{\alpha} \right)^{\frac{1}{\alpha}}} \right\} = \frac{z_{ji}}{\max_i z_{ji}}$$

This implies that each criterion effect z_{ji} is divided by the highest criterion effect for the criterion *j* concerned. Such a procedure guarantees that always one rji-score for each j has value 1, whereas the lowest standardised value depends on the absolute magnitude of the original criterion score z_{ji}; r_{ji} will be 0 only if z_{ji} is 0. This approach is very useful in standardising an evaluation matrix that will be analysed by a weighted summation technique or any other technique which uses the magnitude of the individual scores (standardised effects).

- Min-Max transformations

This third type of standardisation is especially appropriate where a technique is used which performs a pairwise comparison of the criterion scores. The standardisation procedure is performed as:

$$(7.6) \qquad r_{ji} = \frac{z_{ji} - \min_i z_{ji}}{\max_i z_{ji} - \min_i z_{ji}}$$

In such a case differences in scores are measured irrespective of the magnitude of the original "raw" z_{ji}-impacts. This transformation means that the worst criterion score will always be given a standardised value of 0, whereas the best criterion score will always have a standardised value of 1. Evidently, instead of the highest raw score a hypothetical maximum score (*satisfying effect*) may be used both in Eqns. 7.5 and 7.6. Such a hypothetical score may be seen as some kind of achievement level.

- Comparison of transformation methods

In Table 7.1 a numerical example is given of the transformation methods above discussed. It refers to an hypothetical criterion whose effects (measured in relation to 4 different projects) are listed in the first row.

The last column indicates the differences resulting in the effectiveness r_{ji}-scores for each of the transformation performed. Notice that the standardised values obtained by the vector normalisation with α=1 (2[nd] row) are all rather low. In such a case we also have the minimum r_{ji}-range. The latter increases with α=2 (3[rd] row). Since the original effects do not include the value zero, the transformed scores of the first 3 methods do not have a zero either. However, the last row does contain both 0 and 1 values, which is a typical characteristic of Eqn. 7.6.

Min-Max method is largely suitable to be applied to MEA calculations performed via concordance analysis, that carries out a series of pairwise comparisons of the criterion scores. Anyhow, it can be easily shown that the correct use of a method instead of another one does not affect sensitively the ultimate ranking of alternative plans.

STANDARDISATION ACCORDING TO CRITERION DIRECTION

A further aspect to discuss related to standardisation methods is the issue of the *direction* of the criterion effects. For some of the criteria a

Table 7.1 – A numerical example of some standardisation methods

	Projects				
	A	**B**	**C**	**D**	
Original z_{ji}-effects (raw-scores):	**2.5**	**25**	**250**	**500**	
					Effectiveness r_{ji}-range
Vector normalisation (α=1)	0.003	0.032	0.319	0.639	**0.636**
Vector normalisation (α=2), *Eqn. 7.4*	0.004	0.045	0.447	0.893	**0.889**
Linear scale transformation, *Eqn. 7.5*	0.005	0.050	0.500	**1.000**	**0.995**
Min-Max transformation, *Eqn. 7.6*	**0.000**	0.045	0.497	**1.000**	**1.000**

higher criterion effect implies a *better effect*, whereas for other criteria a higher score might imply a *worse effect*. The first kind of criteria are usually called *benefit-criteria*, whereas the second type can be denoted as *cost-criteria*. An example of a benefit criterion is "*the local energy demands directly supplied by the hydro-power plant (in terms of % of the present demand)*", and an example of a cost criterion is "*the specific investment required to install the plant (e.g., in terms of ℤ/MW)* ". An increase in the former effect will undoubtedly be received as positive, while an increase in the latter effect will be obviously seen in a negative way. Anyhow, sometimes it is not so immediate to distinguish between benefit or cost criteria. Let's consider the effect "*length of new access roads that must be constructed to reach the plant*". An increase on such a length could be judged as positive by decision-makers that are actually interested in developing new infrastructure in poor, marginal areas. But there could be some opposite standpoints that tend to see this increase in a negative way because it even implies an increase of the installation costs or an increase of forest areas that will be indirectly damaged by the plant construction.

The above considerations lead to the following practical consequences:

1. when constructing the impact matrix **Z**, the user must be enabled to specify for each criterion which type of direction he is going to consider (**B**: benefit-criterion; **C**: cost-criterion); this means that an additional binary property must be added to criteria formulation;
2. each standardisation method must be accompanied by a consideration of the effect direction, i.e. the effectiveness scores of the cost-criteria must receive the same direction as the benefit-criteria, or vice versa; in other words: the aim is to obtain an effectiveness matrix **R** irrespective of the direction assigned to the original effects; all the r_{ji}-scores must be calculated in such a way that the higher r_{ji}, the better the standardised situation calculated for the *j-th* criterion of the *i-th* project;
3. during the analysis, the user must be enabled to provide an easy change in the criteria direction; such a change necessarily require the calculation of a new **R**-matrix.

The target outlined in the previous point 2 may be done by subtracting the standardised score, whose direction has to be changed (typically a cost-criterion), from one. When all scores have to be formulated according to the direction "the higher, the better", the following transformation must be performed:

$$(7.7)\quad \textit{Directed standardised score} \begin{cases} = r_{ji} & (\textit{benefit-criterion}) \\ = 1 - r_{ji} & (\textit{cost-criterion}) \end{cases}$$

Eqn. 7.7 can be applied to all the standardisation procedures discussed in the previous paragraph. The resulting directed standardised scores can then be further analysed by means of the various multicriteria evaluation techniques.

7.4 CRITERION PRIORITIES: THE WEIGHING SYSTEM

A very important component of MEA concerns the priorities attached to the various criteria. This component reflects the *subjective* part of the input information to be provided to the MEA procedures, trying to reproduce the personal standpoint of the decision maker. Priorities are expressed throughout a weighing system: for each criterion j a relative weight w_j may be determined such that the following additivity condition is satisfied:

$$(7.8)\qquad \sum_{j=1}^{J} w_j = 1$$

Thus the weighing system is essentially represented by a vector $\mathbf{W} = [w_1, w_2, \ldots, w_J]$. When several decision standpoints are considered with the problem at hand, different **W**-vectors will be included into the priority matrix, one vector for each view.

These weights are not necessarily trade-off (or marginal rates of substitution) between alternative criteria. The easiest way to determine these weights is to ask the decision-maker to indicate the relative importance of a certain criterion with respect to the other criteria on a cardinal scale ranging for example from 0 to 10 (an ordinal scale could be even proposed). By standardising these weights relationship assessed by Eqn. 7.8 may be obtained.

It should be noted that the weights are closely related to the unit of measurements of the decision criteria; the most practicable way to avoid dimensional problems is to relate these weights to the effectiveness r_{ji}-scores in **R** matrix. This implies, for example, that a weight attached to environmental quality as such is rather meaningless, but that a weight has to be specified so that it reflects the relative importance attached to the marginal percentage change in environmental quality by the project(s) concerned.

It is clear that the determination of weights is far from an easy task. In fact, two alternative ways are open to assess relative priorities of decision-makers:

- the *implicit* method, based on an *ex post* analysis of revealed preferences;
- the *interview* method, based on *a priori* assessment of priorities by means of interviews.

The interview methods are in general more favourable than the implicit methods owing to the fact that an ex post assessment of relative priorities mostly requires a repetitive decision situation. It should be even noted that the interview method does not lead to "objective" weights, since the evaluation of decision criteria is always co-determined by social, economical and political conditions that form the general background context of the analysis problem at hand. Since, however, an assessment of priority schemes of decision-makers is fraught with difficulties, a sensitivity analysis must be performed on the composition of the weighing system to test the stability of the ultimate results.

The approach here proposed is mostly based upon the use of a weighing system represented by a set of quantitative expressions reflecting the condition stated by Eqn. 7.8. So we have quantitative weight-numbers that permit continuous weight-combinations in order to perform sensitivity analyses on subjective standpoints. The results of these analyses can be represented via an appraisal matrix (Fig. 7.4) or even via graphic metaphors. In the latter case, criteria must be prior clustered (following a hierarchical approach) into homogeneous groups (higher-level criteria) as already discussed.

Suppose we want to cluster the original finite number of criteria (j = 1, 2, ..., *J*) into a finite number of groups (n = 1, 2, ..., *N*). Each group will receive a finite number of criteria (m_n = 1, 2, ..., M_n) so that:

$$(7.9) \qquad \sum_{n=1}^{N} M_n = J$$

The condition assessed by Eqn.7.8 still remains valid, because the original absolute weights are maintained. In fact, when the original *j-th* criterion becomes the m_n*-th* criterion of the *n-th* group, we still have that:

$$(7.8bis) \qquad \sum_{n=1}^{N}\sum_{m_n}^{M_n} w_{n,m_n} = 1$$

The absolute weight of the *n-th* group (g_n) is given by:

$$(7.10) \qquad g_n = \sum_{m_n=1}^{M_n} w_{n,m_n}$$

Here the term "*absolute*" is used to underline the difference with the "*relative*" weight (p_{mn}) that each criterion has within its own group:

$$(7.11) \qquad \sum_{m_n=1}^{M_n} p_{m_n} = 1$$

The link between absolute and relative weights is then assessed by the following:

$$(7.12) \qquad w_{n,m_n} = g_n \cdot p_{m_n}$$

In **Table 7.2** a numerical example is given of the weight-concepts above defined.

The software package that will be presented in the next chapter provides an efficient computer user-friendly interface to group criteria and manage weight assessment. It even performs sensitivity analyses providing graphic-metaphor outputs to study the stability of ultimate rankings according to different weight-standpoints. To do this, only 2 or 3 groups of criteria can be set by the user.

According to the above formula, it is clear that - when the criteria are going to be clustered into groups – there are two alternative possibilities for entering the weighing system of the problem at hand:

1. direct input of the w_j absolute values, when the weights are entered before grouping criteria; group weights g_n and relative weights inside each group p_{mn} will then depend on the distribution of criteria among groups;
2. direct input of the group weights g_n and of the relative weights inside each group p_{mn}, when we want to give more relevance to the effects deriving from the clustering process, that is performed before the weight assignment; absolute weights will then be derived by Eqn.7.12.

Obviously, the two methods do not affect

Criteria	Groups		Absolute Weights	Group Weights	Relative Weights
j	n	m_n	$w_j = w_{n,m_n}$	g_n	p_{m_n}
1	1	*1*	10		*50*
2	1	*2*	2	20	*10*
3	1	*3*	8		*40*
4	2	*1*	6		*23*
5	2	*2*	12	26	*47*
6	2	*3*	4		*15*
7	2	*4*	4		*15*
8	3	*1*	20		*37*
9	3	*2*	2	54	*4*
10	3	*3*	32		*59*
		Total	100	100	

Table 7.2 – A numerical example of weight treatment when grouping criteria

directly the final result. Their choice is rather linked to the approach that the user wishes to follow in defining his own priorities. The second method is evidently more in relation to the application of an hierarchical analysis.

7.5 THE CONCORDANCE ANALYSIS

GENERAL ASPECTS

Most differences in MEA methods arise from the arithmetic procedures to combine the information from the evaluation matrix **Z** with the information from the priority matrix in order to arrive at interpretable conclusions concerning the general quality or desirability of the alternatives under considerations. In some methods the operational simplicity of the arithmetic procedure is stressed, whereas in other methods a more sophisticated approach is favoured to

Table 7.3 – Projects considered in the MEA exercise discussed in the text.

Name of Project	Id. Label	Description
New Project	**NEW**	Installation of a 1.1 MW rated hydropower plant able to produce 5.5 GWh_e/yr. *Advantages*: general low impacts on the environment and the landscape (very few visible structures). *Disadvantages*: high installation costs and plant with a low rated electric power.
Old Project	**OLD**	Installation of a 1.5 MW rated hydropower plant able to produce almost 6.4 GWh_e/yr. *Advantages*: low installation costs and plant with a high rated electric power; *Disadvantages*: general high impacts on the environment and the landscape (many relevant visible structures). "OLD" is for the designing method that recalls traditional approaches, generally irrespective of environment and nature needs.
Left Riverside	**LEFT**	Installation of a 1.05 MW rated hydropower plant able to produce 5.3 GWh_e/yr. *Advantages*: similar to NEW, but with lower intensity; here we also have the lowest installation costs; *Disadvantages*: it has the lowest rated electric power installed. In practice this is a compromise solution between NEW and OLD (the penstock is planned to be installed on river left-side instead of right-side as the previous solutions).
Alternative Zero	**ZERO**	No installation is planned.

	Name of CRITERIA		Unit of measure	Direction (B/C)	Def. h-l group
	Id. Label	Definition			
1	EnPro	Energy produced by the plant	GWh/y	B	ECO
2	EmisAv	CO_2 emission avoided	Mt/y	B	ENV
3	InstPow	Installed capacity	MW	B	TEC
4	InvPow	Specific investment (capacity)	/kW	C	ECO
5	LgtNwRds	Length of new access roads to the plant	km	B	ENV
6	BckLgt	Backwater length in case of mean water	m	C	ENV
7	%DailyTrans	Percentage of the daily water volume transferred from empty to peak hours	%	B	TEC
8	DmHgt	Dam height	m	C	ENV
9	BedLoad	Interruption of bedload transport	%	C	ENV
10	AreaPow	Area used by the powerhouse	m^2	C	ENV
11	PercUndPow	Percentage of underground power-house	%	B	ENV
12	DivLng	Diversion length	km	C	ENV
13	PercInPnst	Percentage of underground penstock or channel	%	B	ENV

Table 7.4 – Criteria considered in the MEA exercise discussed in the text. The tables even indicates a default higher-level group each criterion is assigned to by default (ECO = economic-related group; TEC = technical-related group; ENV = environmental-related group)

avoid an improper use of the information sources. Nevertheless, *every method is based on assumptions which can not often be properly explained nor justified.*

Concordance analysis is a MEA cardinal technique, which uses the *quantitative* properties of the input data. It is based on ranking techniques for the effects of decision criteria related to a set of *distinct* alternative plans. This method is less appropriate when continuous decisions are to be made, but such a case is not typical for comparative evaluation problems of alternative hydropower installations. The method was originally developed in France in the sixties, where it is usually called *Electre*-method (ELimination Et Choix Traduisant la REalitè).

The central aim of this cardinal technique foresees the use as input data of both the impact matrix **Z** and the weight vector **W**. A common

Criteria	Unit of measure	Direction (B/C)	Projects			
			NEW	OLD	LEFT	ZERO
EnPro	*GWh/year*	B	5.50	6.38	5.30	0
EmisAv	CO_2Mt/yr	B	5.50	6.38	5.30	0
InstPow	*MW*	B	1.10	1.50	1.05	0
InvPow	*□/kW*	C	2.488	2.410	2.400	0
LgtNwRds	*m*	B	1,930	0	1,930	0
BckLgt	*m*	C	0	36.00	11.00	0
%DailyTrans	*%*	B	20.00	0	20.00	0
DmHgt	*m*	C	0	1.50	1	0
BedLoad	*%*	C	50.00	75.00	50.00	0
AreaPow	m^2	C	170.00	200.00	180.00	0
PercUndPow	*%*	B	60.00	30.00	50.00	100.00
DivLng	*m*	C	1,400	2,200	1,450	0
PercIntPnstH	*%*	B	65.00	45.00	100.00	100.00

Table 7.5 – Impact matrix **Z** of the numerical example discussed in the text

feature with respect to cost-benefit analysis is that both methods start off from the plan impact matrix which incorporates the outcomes of relevant decision criteria for alternative plans. The weighing schemes of a concordance method, however, differ significantly from monetary measures of a cost-benefit analysis. The introduction of **W** implies that for each pair of plans separately a concordance measure and a discordance measure can be constructed on the basis of which the relative (pairwise) preferences with regard to alternative plans can be determined.

EXERCISING THE METHOD ON A CASE STUDY

Concordance analysis is here described applying its calculation procedures to an example concerning the problem of choosing among 3 different hydropower plant solutions to be installed in a mountain valley in Northern Italy (Val Salarno). There is even a further solution, a "*zero" solution*, that is the situation in which no action is planned. These 4 alternatives are comparatively evaluated taking into consideration 13 criteria of different nature. A brief presentation of projects and criteria is given in **Tables 7.3** and **7.4**, respectively.

The effects of each alternative were brought out from the feasible projects drawn for each solution. The impact matrix **Z** shown in **Table 7.5** was thus constructed.

Different weight vectors **W** were considered. They are shown in **Table 7.6** where a priority matrix for the exercise at hand is presented. Here there are 8 standpoints reflecting different priorities with respect to the higher-level groups in which each criterion can be clustered in. For each criterion the definition of its higher-level group it belongs to is again given in Table 7.4. For simplicity, and apart from the **VIII view** (*Designer's view*), the priorities in the table are even presented throughout integer numbers, in order to make more clear the relative preference assigned to each criterion. The condition established by Eqn.7.8 is always respected normalising such integers to obtain the relative weighing system **W** to be inputted prior MEA calculations. In this way, we can quickly see that the view *Equal* implies the use of the same priorities for each criterion (each with an absolute weight of approx. 7.7%), whilst the view *MoreEco* assigns a double importance to the two Economical-related criteria (i.e., *EnPro* and *InvPow*) when compared with all the other criteria in the analysis. In the *VeryHighEco* view such importance rises up to 20 times as much as the other criteria: this is an extreme standpoint, with EnPro and InvPow that alone collect almost the 80% of the overall

VIEWS			CRITERIA 1	2	3	4	5	6	7	8	9	10	11	12	13
I	**Equal**		1	1	1	1	1	1	1	1	1	1	1	1	1
		(%)	*7.7*	*7.7*	*7.7*	*7.7*	*7.7*	*7.7*	*7.7*	*7.7*	*7.7*	*7.7*	*7.7*	*7.7*	*7.7*
II	**MoreEco**		2	1	1	2	1	1	1	1	1	1	1	1	1
		(%)	*13*	*6.7*	*6.7*	*13*	*6.7*	*6.7*	*6.7*	*6.7*	*6.7*	*6.7*	*6.7*	*6.7*	*6.7*
III	**VeryHighEco**		20	1	1	20	1	1	1	1	1	1	1	1	1
		(%)	*39*	*2*	*2*	*39*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*
IV	**HighEcoLowTec**		11	2	1	11	2	2	1	1	2	1	1	2	1
		(%)	*29*	*5*	*3*	*29*	*5*	*5*	*3*	*3*	*5*	*3*	*3*	*5*	*2*
V	**LowTec**		6	5	1	6	5	5	1	1	5	1	1	5	1
		(%)	*14*	*12*	*2*	*14*	*12*	*12*	*2*	*2*	*12*	*2*	*2*	*12*	*2*
VI	**HighTec**		3	1	5	3	1	1	5	5	1	5	5	2	5
		(%)	*7*	*2*	*12*	*7*	*2*	*2*	*12*	*12*	*2*	*12*	*12*	*5*	*13*
VII	**LowEnv**		4	1	2	4	1	1	2	2	1	2	2	1	2
		(%)	*16*	*4*	*8*	*16*	*4*	*4*	*8*	*8*	*4*	*8*	*8*	*4*	*8*
VIII	**Designer's view**														
		(%)	*14*	*8*	*9*	*8*	*10*	*5*	*2*	*5*	*2*	*7*	*9*	*9*	*12*

Table 7.6 – Priority matrix attached to the numerical example discussed in the text. Only the last view in the table is entered on a 0..100 rational scale. All the other priorities are expressed as integer values underlying the relative differences among criterion preferences.

importance "budget". In every type of application the *Equal* view could be a good starting standpoint.

Other extreme standpoints are, for example, represented by the **V** and **VI** views, reflecting a low and a high interest for the technical-related criteria, respectively. In the former view (*LowTec*) each criterion related to technical aspects is assigned with a relative importance that is 5-6 times as low as possible the ones assigned to the other economical and environmental criteria; in the latter view (*HighTec*), such technical aspects have up to 5 times more importance than the other aspects.

It is essential to underline now that all the views assessed in the exercise here discussed (apart from the *Designer's View*) have the common characteristic of maintaining equal *relative weights* within the criteria belonging to the same higher-level group. Here the "relative weight" must be intended in the terms defined by Eqn.7.11. In other words: the criteria clustered into the same group have always the same absolute weight. It can be easily seen that this is not true for the view VIII. The views from I to VII must simply be seen as an exercise to explore the sensitivity of the method.

These views will be combined with the impact matrix of Table 7.5 to produce a final appraisal matrix. This will be even integrated by graphical sensitivity analysis. Nevertheless, the numerical example we are going to present and discuss will refer to the figures listed in **view VIII**.

CONCORDANCE CALCULATION ALGORITHMS

Calculation steps

The solution of every MEA problem via concordance analysis must be implemented throughout a series of successive steps:

i. Standardisation;
ii. Concordance and Discordance sets;
iii. Concordance matrix;
iv. Discordance matrix;
v. Concordance dominance index;
vi. Discordance dominance index;
vii. Elimination and selection of alternatives.

Several runs are required to perform sensitivity analysis, modifying effects in **Z** or weights in **W**. When only the content of **W** is modified (e.g., passing from one view to another in the priority matrix), only the steps from (iii) to (vii) must be repeated. If changes consider

Criteria	Projects			
	NEW	OLD	LEFT	ZERO
EnPro	0.8621	1	0.8307	0
EmisAv	0.8621	1	0.8307	0
InstPow	0.7333	1	0.7000	0
InvPow	0	0.0314	0.354	1
LgtNwRds	1	0	1	0
BckLgt	1	0	0.6944	1
%DailyTrans	1	0	1	0
DmHgt	1	0	0.3333	1
BedLoad	0.3333	0	0.3333	1
AreaPow	0.1500	0	0.100	1
PercUndPow	0.4286	0	0.2857	1
DivLng	0.3636	0	0.3409	1
PercIntPnstH	0.3636	0	1	1

Table 7.7 – Effectiveness matrix R calculated when the Min.Max standardisation procedure is applied to figures in Table 7.5

even figures in **Z**, all the steps from (i) to (vii) must be re-performed.

The standardisation procedures are the same described at 7.3. Here it was decided to apply the Min-Max method. When Eqns. 7.6 and 7.7 are applied to all the original outcomes of Table 7.5, the effectiveness matrix **R** presented in **Table 7.7** is produced.

Concordance and Discordance sets

The basic approach of concordance analysis involves a pairwise comparison — in terms of each criterion taken individually — of all the alternative plans in the matrix **R**. From each comparison between two plans *i* and *k* we obtain a Concordance set $\mathbf{C}_{ik}$ and a Discordance set $\mathbf{D}_{ik}$.

The Concordance set includes all the criteria *j* for which plan *i* is preferable to plan *k*:

$$(7.13) \qquad C_{ik} = \{ j \mid r_{ji} > r_{jk} \}$$

Conversely, the Discordance set is defined as:

$$(7.14) \qquad D_{ik} = \{ j \mid r_{ji} < r_{jk} \}$$

By definition, the following relationship exists between the two sets:

$$(7.15) \qquad C_{ik} = D_{ki}$$

In fact, when $r_{ji} = r_{jk}$ the corresponding criterion will not belong to either of the two sets. For example, from Table 7.7 it emerges that:

$C_{NEW,LEFT} = C_{13} = \{1,2,3,6,8,10,11,12\}$
and
$D_{ZERO,OLD} = D_{42} = \{1, 2, 3\}$.

Positive aspects of alternatives

They are considered by the concordance matrix and the Concordance Dominance Index. It is clear that the concordance set $\mathbf{C}_{ik}$ will contain more elements as plan *i* dominates plan *k* with regard to more criteria. The relative dominance can now be represented by means of a **concordance index (c_{ik})** that can be defined as:

$$(7.16) \qquad c_{ik} = \sum_{j \in C_{ik}} w_j \ , \quad \forall i \neq k$$

In other words: the concordance index of plan *i* with respect to plan *k* is equal to the sum of the weights attached to the criteria belonging to the concordance set of plan *i* with respect to plan *k*. Consequently, the concordance index c_{ik} can be interpreted as the relative dominance of plan *i* above *k*: a high value of c_{ik} indicates that for the criteria belonging to the concordance set plan i is preferred to plan k; if cik = 1, there is a complete dominance of plan i with respect to plan k ; if $c_{ik} = 0$, plan i is worse than k for any criterion.

All the concordance indices c_{ik} are then included in a (non-symmetric, square) **concordance matrix C** of order **I** (= number of alternatives):

$$(7.17) \quad \mathbf{C} = \begin{bmatrix} - & c_{12} & \cdots & c_{1I} \\ c_{21} & - & \cdots & \cdots \\ \cdots & \cdots & - & \cdots \\ c_{I1} & \cdots & \cdots & - \end{bmatrix}$$

Each element c_{ik} indicates the relative dominance of plan i with respect to plan k, and is calculated by summing the weights associated with the criteria that belong to the concordance set $\mathbf{C_{ik}}$ **(Table 7.8)**.

It is clear that, the greater the value of $\mathbf{c_{ik}}$ with respect to $\mathbf{c_{ki}}$, the better plan i will prove to be in comparison with k. The difference ($\mathbf{c_{ik}}$ - $\mathbf{c_{ki}}$) therefore provides a measure of the relative dominance of i as compared with k. Hence, in our example, plan 1 (*New Project*) is more advantageous than plan 2 (*Old Project*) because:

$$c_{12} - c_{21} = 0.61 - 0.39 = 0.22 > 0$$

After making all the pairwise comparisons between alternative plans, a **Concordance Dominance Index ($\mathbf{c_i}$)** is calculated as follows:

$$(7.18) \quad c_i = \sum_{k=I}^{I} c_{ik} - \sum_{k=1}^{I} c_{ki} \;, \forall k \neq i$$

The terms Σc_{ik} and Σc_{ki} represent, respectively, the row and column sums of concordance matrix **C** (Table 7.8). The row sum expresses the absolute dominance of i with respect to all alternative plans k. Conversely, the column sum expresses the absolute dominance of the set of alternatives k with respect to i.

Clearly, a positive value of c_i reflects a dominance of plan i with respect to all other plans, the dominance being stronger as c_i is higher. Consequently, the plan to be selected as the most "appropriate" one on the basis of the concordance information should satisfy the condition: $\mathbf{max_i\ c_i}$. All other plans can be selected in a decreasing order of concordance dominance. A **preference ranking** order is thus obtained. In our example, plan 1 (*New Project*) proves to be most preferable, with a concordance dominance index:

$$c_1 = 1.70 - 1.06 = 0.64 > 0$$

that is higher than all the others.

Conversely, plan 2 (*Old Project*) results to be the worst solution to be preferred, having the lowest concordance dominance index:

$$c_2 = 1.01 - 1.87 = -0.86 < 0$$

Negative aspects of alternatives

The above ranking only takes into account the positive aspects of the various plans, but tells us nothing about their weak points. In fact, a comparison of two plan i and k leads in general to the conclusion that some effects of i are better than k, but that other effects of i are worse than k. Therefore, in addition to a measure for the relative dominance of i with respect to k, an index reflecting the extent to which plan i is worse than k may be defined. This means to include into the analysis also the plan negative aspects throughout the construction of discordance matrices and the calculation of Discordance Dominance Indeces, all derived from the discordance sets.

Different methods for calculating the discordance index $\mathbf{d_{ik}}$ have been suggested, for a variety of applications and purposes. A first method calculates the **simple discordance index** as

Table 7.8 – Concordance Matrix (c_i = concordance dominance index)

	NEW	OLD	LEFT	ZERO	Σ	c_i
NEW	0	0.6100	0.6600	0.4300	*1.700*	**0.6400**
OLD	0.3900	0	0.3100	0.3100	*1.0100*	**-0.8600**
LEFT	0.2000	0.6900	0	0.4300	*1.3200*	**-0.1000**
ZERO	0.4700	0.5700	0.4500	0	*1.4900*	**0.3200**
Σ	*1.0600*	*1.8700*	*1.4200*	*1.1700*		

follows:

$$(7.19) \qquad d_{ik} = \max_{j \in D_{ik}} \left(\frac{|z_{ji} - z_{jk}|}{d_j^{max}} \right)$$

where the denominator is defined as:

$$(7.20) \qquad d_j^{max} = \max_{0 \le 1, k \le I} |z_{ji} - z_{jk}|$$

Analogously to the concordance index defined by Eqn.7.16, it is easily seen that $0 \le d_{ik} \le 1$. The discordance measures the relative discrepancy in the effects of 2 alternative plans, at least as far as the elements of the discordance set are concerned. A maximum discrepancy of plan *i* with respect to *k* implies that $d_{ik}=1$, while a minimum discrepancy implies that $d_{ik}=0$. The elements d_{ik} can again be included in a (non-symmetric, square) **discordance matrix D** (of order I):

$$(7.21) \qquad \mathbf{D} = \begin{bmatrix} - & d_{12} & \dots & d_{1I} \\ d_{21} & - & \dots & \dots \\ \dots & \dots & - & \dots \\ d_{I1} & \dots & \dots & - \end{bmatrix}$$

As far as the example here discussed, let's consider the discordance comparison between plans 3 and 2, that is discordance set

$\mathbf{D_{32}} = \mathbf{D_{LEFT,OLD}} = \{ 1, 2, 3 \}$.

Based upon on the original figures of the impact matrix Z (Table 7.5), here we have that the absolute values of the effect-differences between plan 3 and 2 for all the criteria included in the discordance set (j = 1, 2 and 3) are calculated as follows:

$|z_{13} - z_{12}| = |5.30 - 6.38| = 1.08$, for j=1, EnPro;
$|z_{23} - z_{22}| = |5.30 - 6.38| = 1.08$, for j=2, EmisAv;
$|z_{33} - z_{32}| = |1.05 - 1.50| = 0.45$, for j=3, InstPow.

On its side, the maximum difference (discrepancy) resulting for each criterion included in $\mathbf{D_{32}}$ is given by the followings:

$d_1^{max} = |z_{12} - z_{14}| = |6.38 - 0| = 6.38;$
$d_2^{max} = |z_{22} - z_{24}| = |6.38 - 0| = 6.38;$
$d_3^{max} = |z_{32} - z_{34}| = |1.50 - 0| = 1.50.$

Then according to Eqn.7.19 the following ratios can be finally calculated:

for j=1: 1.08/6.38=0.17
for j=2: 1.08/6.38=0.17
for j=3: 0.45/1.50=0.30.

The discordance index corresponds to the maximum value resulting from such ratios. Thus we have $d_{32} = 0.30$. In an analogous way we can calculate $d_{42} = 1$. This means that plan 3 (*Left Riverside*) is worse than plan 2 (*Old Project*) in relation to some criteria that however cause not relevant discrepancies. The highest one must be put in relation to the criterion j=3 (InstPow = Power Installed): such a discrepancy is equal to only the 30% of the maximum discrepancy that can be observed among all the plans. On the other side, a maximum negative discrepancy exists when plans 4 and 2 are compared.

Note that the discordance index d_{ik} can be used using the r_{ji} standardised values of the effectiveness matrix instead of the original effects z_{ji}. In such a case, and when the Min-Max transformation is applied to construct matrix **R**, the following formula substituting Eqn.7.19 can be obtained:

$$(7.19\,\text{bis}) \qquad d_{ik} = \max_{j \in D_{ik}} \left(|r_{ji} - r_{jk}| \right)$$

In fact, Eqn.7.20 always gives $d_j^{max} = 1$ as result, because the Min-Max method always provides a maximum discrepancy equal to 1.

In a way analogous to Eqn.7.18 a **Discordance Dominance Index d_i** can be constructed:

$$(7.22) \qquad d_i = \sum_{k=1}^{I} d_{ik} - \sum_{k=1}^{I} d_{ki} \ , \ \forall k \neq i$$

This index is a measure of the discordance dominance: a low value of d_i (i.e., a negative value) implies a stronger dominance of plan *i*, at least as far as the discordance information is concerned. The ultimate selection criterion for a plan on the basis of a discordance dominance is: $\mathbf{min_i d_i}$. In a similar way the remaining plans can be ranked in a decreasing order of discordance dominance.

For the example here discussed, the discordance matrix constructed throughout the discordance index defined by Eqn.7.19 is presented in **Table 7.9**.

Since there are different methods to calculate discordance indices, the one above presented will be more specifically called synthetic **Simple Discordance** index ($\mathbf{d_{i,SD}}$), to be distinguished by the others presented here after.

In our example, plan 1 (*New Project*) still proves to be preferable, with a simple discordance dominance index:

$d_{1,SD} = 1.9030 - 2.6667 = -0.7636 < 0$

that is lower than all the others.

	NEW	OLD	LEFT	ZERO	Σ	$d_{i,SD}$
NEW	0	0.2667	0.6364	1	*1.9030*	**-0.7636**
OLD	1	0	1	1	*3.000*	**1.4333**
LEFT	0.6667	0.300	0	0.9646	*1.9313*	**-0.7051**
ZERO	1	1	1	0	*3.000*	**0.0354**
Σ	*2.6667*	*1.5667*	*2.6364*	*2.9646*		

Table 7.9 – Simple Discordance Dominance Matrix ($d_{i,SD}$ = synthetic discordance dominance index).

Conversely, plan 2 (*Old Project*) still results to be the worst solution to be preferred, having the highest discordance dominance index:

$d_{2,SD} = 3.0000 - 1.5667 = 1.4333 > 0.$

Thus the first and the last position of the plan preference order are exactly the same for the concordance and discordance measures.

Another method to define the discordance index is an extension of Eqn.7.19, carried out by taking into account the relative weights attached to the effects of the successive criteria. This **Weighted Discordance Index** is equal to:

$$(7.23) \qquad d_{ik} = \max_{j \in D_{ik}} \left(\frac{w_j \cdot |r_{ji} - r_{jk}|}{d^{max}} \right)$$

where d^{max} is defined as:

$$(7.24) \qquad d^{max} = \max_{\substack{j \in D_{ik} \\ (i,k)}} \left(w_j \cdot |r_{ji} - r_{jk}| \right)$$

Here the standardised scores r_{ji} are always used, because the numerator and the denominator of Eqn.7.23 are not necessarily related to the same decision criterion. Again, note that when the Min-Max transformation is used, d^{max} is always equal to the highest weight-value w_j assigned to one of the criteria belonging to the discordance set D_{ik}. In fact $\max |r_{ji} - r_{jk}| = 1$.

For example, if we consider again the already mentioned discordance set $D_{32}=\{1,2,3\}$, the calculation of the weighted discordance index $d_{32,SWD}$ is carried out throughout the following steps:

for j=1: $w_1 \cdot |r_{13} - r_{12}| = 0.14 \cdot |0.8307-1| = 0.0237;$

for j=2: $w_2 \cdot |r_{23} - r_{22}| = 0.08 \cdot |0.8307-1| = 0.0135;$

for j=3: $w_3 \cdot |r_{33} - r_{32}| = 0.09 \cdot |0.7000-1| = 0.0270.$

On its hand, d^{max} is equal to the highest weight value assigned to the 3 criteria included into the discordance set, that is $d^{max} = 0.14$. According to Eqn. 7.23, the weighted discordance index is finally calculated as:

$d_{32,WD} = 0.0270/0.14 = 0.1929.$

The relative weighted discordance matrix is presented in **Table 7.10**, together with the values of the synthetic indices $d_{i,WD}$, always calculated based upon Eqn.7.22.

The above 2 discordance indices ("simple" and "weighted") are only related to a *maximum discrepancy* among project effects. Instead of a maximum discrepancy, in general a more representative picture of discordance differences is obtained by defining two *aggregate discordance indices*, both based on all differences among effects of criteria belonging to the discordance set.

The first one is the **Simple Aggregate Discordance index** and is equal to:

Table 7.10 – Weighted Discordance Matrix ($d_{i,WD}$ = synthetic weighted discordance index).

	NEW	OLD	LEFT	ZERO	Σ	$d_{i,WD}$
NEW	0	0.1714	0.5455	0.5714	*1.2883*	**-0.5261**
OLD	0.7143	0	0.8571	0.8571	*2.4286*	**1.0643**
LEFT	0.2381	0.1929	0	0.5512	*0.9822*	**-1.2511**
ZERO	0.8621	1	0.8307	0	*2.6928*	**0.7130**
Σ	*1.8144*	*1.3643*	*2.2333*	*1.9798*		

$$(7.25)\qquad d_{ik} = \frac{\sum_{j \in D_{ik}} \left(\frac{\left| r_{ji} - r_{jk} \right|}{Gd_j^{max}} \right)}{f}$$

where f is defined as:

$$(7.26)\qquad f = \max_{(i,k)}(f_{ik})$$

and where f_{ik} represents the number of criteria belonging to the discordance set D_{ik}. In addition, Gd_j^{max} is defined as:

$$(7.27)\qquad Gd_j^{max} = \max_{(i,k)} \left| r_{ji} - r_{jk} \right|$$

Also in this case, when the Min-Max transformation is applied to obtain the **R** matrix, we always have $Gd_j^{max} = 1$. All considered, this aggregate index represents a sort of "average" among all the discrepancies that can be calculated among the effects of the criteria included in the discordance set. In order to guarantee that this index falls between 0 and 1, it is divided by f. In other words, this latter represents the maximum number of criteria that can be included in all the D_{ik} that can be constructed for the problem at hand.

The various f_{ik} for the example we are dealing with are given in **Table 7.11**.

Thus we have that $f = 10$.

Continuing with the example of the discordance set D_{32}, the application of Eqn.7.25 foresees the following calculations:

for j=1: $| r_{13} - r_{12} | = | 0.8307 - 1 | = 0.1693$;

for j=2: $| r_{23} - r_{22} | = | 0.8307 - 1 | = 0.1693$;

for j=3: $| r_{33} - r_{32} | = | 0.7000 - 1 | = 0.3000$.

Thus, the simple aggregate discordance index is equal to:

$d_{32,AD} = (0.1693 + 0.1693 + 0.3000)/10 = 0.0639$.

This result indicates that the negative aspects of plan 3 (*Left Riverside*) with respect to plan 2 (*Old Project*) are not very relevant. All the indices are then collected into the relative simple aggregated discordance matrix, presented in **Table 7.12** together with the values of the synthetic indices $d_{i,AD}$, always calculated starting from Eqn.7.22.

A further aggregate index can be obtained adjusting $d_{i,AD}$ for weighted criteria in the following way:

$$(7.28)\qquad d_{ik} = \frac{\sum_{j \in D_{ik}} \left(\frac{w_j \cdot \left| r_{ji} - r_{jk} \right|}{d^{max}} \right)}{f}$$

Here the parameter d_j^{max} is always calculated by Eqn.7.24.

This last index is named **Aggregated Weighted Discordance Index**, and can be seen as the most satisfying in combining effect discrepancies with the relative importance of the criteria generating such discrepancies.

Continuing with the previous D_{32}-example, we can reconsider the steps that have been already calculated for the above weighted discordance index. The current index can be then cal-

Table 7.11 – Number of criteria – f_{ik} - included in the various discordance set D_{ik} that can be identified for the example discussed in the text

	Projects			
Projects	*1.NEW*	*2.OLD*	*3.LEFT*	*4.ZERO*
1.NEW	-	4	2	6
2.OLD	9	-	10	8
3.LEFT	8	3	-	7
4.ZERO	5	5	5	-

Table 7.12 – Aggregated Discordance Matrix ($d_{i,AD}$ = synthetic aggregated discordance index).

	NEW	OLD	LEFT	ZERO	Σ	$d_{i,AD}$
NEW	0	0.0574	0.0672	0.4361	*0.5606*	**-0.5774**
OLD	0.5639	0	0.5092	0.7969	*1.8700*	**1.4487**
LEFT	0.1284	0.0639	0	0.4877	*0.6799*	**-0.3326**
ZERO	0.4457	0.300	0.4361	0	*1.1819*	**-0.5387**
Σ	*1.1380*	*0.4212*	*1.0125*	*1.7206*		

	NEW	OLD	LEFT	ZERO	Σ	$d_{i,AWD}$
NEW	0	0.0406	0.0566	0.2414	*0.3385*	**-0.2362**
OLD	0.2515	0	0.2584	0.4054	*0.9153*	**0.6073**
LEFT	0.0549	0.0459	0	0.2327	*0.3335*	**-0.2428**
ZERO	0.2683	0.2214	0.2613	0	*0.7510*	**-0.1284**
Σ	*0.5748*	*0.3079*	*0.5762*	*0.8794*		

Table 7.13 – Aggregated Weighted Discordance Matrix ($d_{i,AWD}$ = synthetic aggregated weighted discordance index).

culated as:

$d_{32,AWD} = [(0.0237 + 0.0135 + 0.0270)/ /0.14]/10 = [0.4586]/10 = 0.0459.$

The relative aggregated weighted discordance matrix is presented in **Table 7.13**, together with the values of the synthetic indices $d_{i,AWD}$, always calculated on the basis of Eqn.7.22.

The final values of $d_{i,AWD}$ show that plan 3 (*Left Riverside*) proves to be most preferable as far as the weighted aggregate discordance measure is concerned. In fact, we obtain a value of the index:

$d_{3,AWD} = 0.3335 - 0.5762 = -0.2428 < 0$

that is lower than all the others. Nevertheless, plan 1 (*New Project*) also has a quite satisfying index value:

$d_{1,AWD} = 0.3385 - 0.5748 = -0.2362 < 0$

very similar to plan 3, thus reconfirming the good final ranking position obtained with the other discordance indices and with the concordance dominance index.

Conversely, plan 2 (*Old Project*) still results to be the worst solution to be preferred, having the highest (and the only positive) aggregate weighted discordance index:

$d_{2,AWD} = 0.9153 - 0.3079 = 0.6073 > 0.$

Thus the first and the last position of the plan preference order reflect similar results for the concordance and discordance measures.

Elimination and selection of plans

A final preference ranking of the various alternatives is obtained by combining the results of the discordance and concordance approaches. This is done by merging their partial score rankings. We may then proceed to either discard the least favourable plans or to select the one (or ones) which are most appropriate.

The rankings may be merged in several different ways. For example: choosing the plan which has the highest average ranking in both the concordance and discordance dominance procedure. In such a way, we would arrive to select plan 1 (*New Project*). Clearly, other selection strategies are also possible depending on the evaluation of the concordance and discordance dominance by the decision maker.

A summary of the final ranking preference orders obtained by the difference indices discussed above is given in **Table 7.14.**

A comparison evaluation of the various preference orders confirm the strong interest for selecting plan 1 (*New Project*) with the simultaneous rejection of plan 2 (*Old Project*) that gains the last position with all the indices. On their hands, plan 3 and 4 (*Left Riverside* and *Zero Alternative*) compete for the 2nd and 3rd position. This is because when weighted discor-

Table 7.14 – Summary of concordance and discordance rankings. The final ranking obtained according the Global Synthetic Index is given as well.

	c_i		$d_{i,SD}$		$d_{i,WD}$		$d_{i,AD}$		$d_{i,AWD}$		GS_i	
NEW	1	*0.6400*	1	*-0.7636*	2	*-0.5261*	1	*-0.5774*	2	*-0.2362*	1	*0.8762*
OLD	4	*-0.8600*	4	*1.433*	4	*1.0643*	4	*1.4487*	4	*0.6073*	4	*-1.4673*
LEFT	3	*-0.100*	2	*-0.7051*	1	*-1.2511*	3	*-0.3326*	1	*-0.2428*	3	*0.1428*
ZERO	2	*0.3200*	3	*0.0354*	3	*0.7130*	2	*-0.5387*	3	*-0.1284*	2	*0.4484*

dance indices ($d_{i,SWD}$ and $d_{i,AWD}$) are used to provide the final ranking, plan 3 always gains the best position, resulting even better than plan 1 (2nd position). Plan LEFT and ZERO are typical compromise solutions, whose evaluation would require further sensitivity analysis, mainly on the composition of the weighing system.

In any case, we can single out the plans with high values of $\mathbf{c_i}$ and examine the values of their various discordance indices, in light of their specific characteristics. From the above definitions of these indices we can summarise that:

a) The *simple and weighted discordance indices* ($\mathbf{d_{i,SD}}$ and $\mathbf{d_{i,WD}}$) function as indicators, drawing attention to any problems (in connection with a specific criterion) that may be avoided by opting for a different plan. These are indicators focusing the attention on the maximum discrepancies. Note, for example, that in Table 7.9 (simple discordance dominance matrix) plans 1 and 3 (*New Project* and *Left Riverside*, respectively) very rarely have row indices that are equal to 1. This means that there are very few criteria for which these plans are the "least preferable". More precisely: plan1 has an evident weak point only when compared with plan 4, whilst plan 3 does not have any absolute weak point. The opposite is true for plans 2 and 4 (*Old Project* and *Zero Alternative*) which has 3 absolute weak points out of a total of 3 possible comparisons. This is even evident looking at the column indicating the row sum, reaching the maximum value (i.e., 3) in the case of plan 2 and 4. The weighted discordance indices (Table 7.10), on their hands, reflect the same behaviour, modified considering the relative importance of the criteria included in the pairwise comparisons. Also in this case, a high row sum indicating the presence of weak points associated to relevant (say important) criteria results for plans 2 and 4.

b) Conversely, the *aggregate discordance indices* ($\mathbf{d_{i,AD}}$) identify the plans that offer the best level of compromise among the alternatives at hand; in fact they overcome the approach of the "maximum discrepancy" because they also take into account the absolute value of all the effects associated to the criteria included in the discordance set. Thus plan 4 (*Zero Alternative*), which has many absolute weak points, nevertheless obtains a satisfying rating in Table 7.12. This is because its weaknesses are derived from discordance sets that contain a number of criteria (5 in average, as stated in Table 7.11) that is low if compared with the number of criteria of the other plans (only plan 1 has an ave. lower value, viz. 4). For this reason, plan 4 proves to have an aggregate discordance index (-0.54) that is better than the one of plan 3 (-0.33), in spite of the fact that the latter gains a more satisfying discordance index (both simple and weighted) when only the maximum discrepancies are considered.

c) The *weighted aggregate discordance index* ($\mathbf{d_{i,AWD}}$) is the one most formally similar to the concordance index. In fact, as both indices take weights into account, not only do they serve as predictors of the success or failure of a plan, but they may also be interpreted on a scale that quantifies the degree of success or failure. Thus, this index can be seen as the most explanatory among the discordance indicators, because matches weights and averaged discrepancy. Again in the case of plan 4, this causes the above advantages to be attenuated by the fact that their associated criteria have low importance. For this plan, the net result is a level of preference (say, the index $d_{i,AWD}$ = - 0.13) that is worse than the one resulting for plan 3 (-0.24).

In connection with this last point, it is possible to calculate yet another final score by algebraically combining the concordance dominance index and the weighted aggregate discordance index. This score provides integrated information on positive and negative aspects of each plan, and can be named **Global Synthetic Index ($\mathbf{GS_i}$)** that is given by:

$$GS_i = c_i - d_{i,AWD} \qquad (7.29)$$

This score always verifies the condition $\Sigma GS_i = 0$, and hence the final decision should favour those plans with $GS_i > 0$. For the problem at hand, the final GSi scores are again given in Table 7.13. It can be easily seen that this new index does not substantially alter the rankings given by concordance and discordance indicators considered alone. The preference for *New Project* is once again confirmed, while the last position is again assigned to *Old Project*, the only plan resulting with a negative global synthetic (GS_2 = -1.47). Now, *Zero Alternative* and *Left Riverside* are ranked in the 2nd and 3rd posi-

	Views	Projects NEW	OLD	LEFT	ZERO
I	Equal	*1.35*	*-2.76*	*0.25*	*1.16*
		1	4	3	2
II	MoreEco	*0.83*	*-1.74*	*0.09*	*0.82*
		1	4	3	2
III	VeryHighEco	*-0.54*	*0.36*	*-0.03*	*0.21*
		4	1	3	2
IV	HighEcoLowTec	*-0.05*	*-0.29*	*-0.03*	*0.37*
		3	4	2	1
V	LowTec	*0.85*	*-1.56*	*0.05*	*0.66*
		1	4	3	2
VI	HighTec	*1.12*	*-2.35*	*0.16*	*1.07*
		2	4	3	1
VII	LowEnv	*0.59*	*-1.42*	*0.06*	*0.77*
		2	4	3	1
VIII	Designer's View	*0.88*	*-1.47*	*0.14*	*0.45*
		1	4	3	2

Table 7.15 – Appraisal Matrix of the problem discussed in the text. The figures in italic correspond to the global sysnthetic index GS_i, whilst the integers provide the rank in the final preference order (1=best position; 4 = worst position)

tion, respectively; thus reconfirming the ranking order already established by the concordance dominance indexes.

We must keep in mind, though, that the various result tables are not intended to provide an **automatic** solution to the decision-making problem. The underlying presupposition is that this method is an instrument for assisting decision-makers faced with complex situations, especially when the available data is hazy. As such, it must be used to perform sensitivity analysis, to ascertain the stability of the choices made.

The construction of the above defined Appraisal Matrix just tries to satisfy this need. For the problem at hand, such a matrix is given in **Table 7.15**. The views included are the one established in the Priority Matrix presented in Table 7.6. We must remind that all the calculations performed in the above paragraphs were only based upon the weighing system (vector **W**) corresponding to the Designer's View (View VIII, in Table 7.6).

The appraisal matrix combines the priority matrix with the outcomes of the impact matrix (Table 7.5); it provides final scores and ranks for all the plans against each view considered in the problem at hand. Here, global synthetic indexes GS_i were used as final scores.

A part from extreme standpoints, the most preferred solution is still plan 1 (*New Project*) that gains the best position 5 times out 8. Conversely, the worst position is generally achieved by plan 2 (*Old Project*), being the last ranked plan 7 times out 8. Only in correspondence of a very extreme standpoint (*VeryHighEco*) it is able to gain the preferred position, with plan 1 here assigned to the worst one.

The final plan selection should meet the satisfaction of a number of views as many as possible. Thus, a very simple method that can be adopted to identify the "best compromise" ranked preference order is to rank the different plans according to the highest frequency obtained by each ranking position. In our case, the solution can be easily achieved because we have the situation summarised in **Table 7.16**, that is:

Table 7.16 – Summary of the ranked position frequencies obtained in the appraisal matrix of Table 7.14

Ranked position	Projects *NEW*	*OLD*	*LEFT*	*ZERO*
1st	5	1	0	3
2nd	1	0	1	5
3rd	1	0	7	0
4th	1	7	0	0

Thus, the definitive plan preference order can be stated as:

1. NEW (rank position "1" in 5 cases out 8);
2. ZERO (rank position "2" in 5 cases out 8);
3. LEFT (rank position "3" in 7 cases out 8);
4. OLD (rank position "4" in 7 cases out 8).

7.6 THE SENSITIVITY ANALYSIS.

NEEDS OF BETTER DETAILS

The concordance analysis is capable of taking into account a variety of information on diverse plans, decision criteria and priorities. In general, it appears to be a meaningful procedure to carry out a sensitivity analysis regarding the input of information, particularly the weighing schemes. This implies that the robustness of the model can be tested by means of sensitivity tests on individual values of the weights.

The construction of an Appraisal Matrix already goes in such a direction. But in this matrix only discrete, well defined weighing systems can be included. Profiting of the properties established by Eqn.7.8, more exhaustive analysis can be carried out, even using graphic metaphors.

GROUPING CRITERIA

To perform sensitivity analyses, criteria must be previously clustered into homogeneous groups (higher-level criteria). This matter has been already deeply discussed at paragraph 7.4.

A criterion-grouping procedure must respect the following steps:

1. select the <u>*number of homogeneous group*</u> (here only the case of 2 or 3 groups will be treated);
2. select the <u>*relative weight*</u> that must be assigned to the criteria belonging to the same group;
3. select the <u>*absolute weight*</u> to be globally assigned to each group.

The absolute weight of each criterion will be finally determined combining the above information by means of Eqn.7.12.

ANALYSIS WITH 2 HOMOGENEOUS GROUPS

Suppose we want to evaluate a finite number of alternative hydropower projects i (i = 1, 2, ..., I) by means of a finite number of criteria j (j = 1, 2, ..., J) clustered in N = 2 groups, each with M_n criteria:

$$(7.30) \qquad M_1 + M_2 = J$$

Suppose we have a specific strategy to set the relative weights of criteria inside each group, that is:

$$(7.31) \qquad \sum_{m_1=1}^{M_1} p_{m_1} = 1 \quad \text{and} \quad \sum_{m_2=1}^{M_2} p_{m_2} = 1$$

Let's also assume that we want to perform a finite number *(H+1)* of MEA analyses (say, concordance analyses with the calculation of all the concordance and discordance indexes), each being characterised by different group weight values (g_n), but always reflecting in the *h*-th calculation the basic condition:

$$(7.32) \qquad g_{1,h} + g_{2,h} = 1 \ (or 100\%)$$

Obviously, if a continuous complementary variation in $g_{1,h}$ and $g_{2,h}$ is required, the following parameters must be taken into account when determining the value of H: **a)** the maximum and the minimum group values (g_{max} and g_{min}, respectively) we want to assign to g_1 and g_2; and **b)** the weight group variation Δg we want to provide complementary to $g_{1,h}$ and $g_{2,h}$ when passing from the *h*-th to the *(h+1)*-th calculation. Parameter H is then given by:

$$(7.33) \qquad H = \frac{g_{max} - g_{min}}{\Delta g}$$

If the sensitivity analysis on the weighing system intends to explore as many possibilities as possible (even including very extreme standpoints), in general the following conditions are set:

g_{max} = 1 (or 100%) and $g_{min} = 0$.

Thus, the choice of Δg is almost compulsory being obliged to obtain an integer value of H. Only the values in following set can be assigned:

$\Delta g = \{1, 2, 4, 5, 10, 20, 25, 50\}$ *(all in %).*

Respectively, the following H-values are then obtained:

H = {100, 50, 25, 10, 5, 4, 2}.

Generally it is not worthwhile to consider variation values $\Delta g<1$ that would cause H>100.

If a sensitivity analyses with Δg=1% is desired, 101 independent concordance analyses must be performed. In fact, the following g_n-combination will be independently considered:

Iteration	*Absolute weight of the 1st group*	*Absolute weight of the 2nd group*
1	$g_{1,1} = 0$	$g_{2,1} = 100$
2	$g_{1,1} = 1$	$g_{2,1} = 99$
...	...	...
h	$g_{1,h} = (h-1)\cdot\Delta g$	$g_{2,h} = 100 - (h-1)\cdot\Delta g$
...	...	...
H	$g_{1,H} = (H-1)\cdot\Delta g$	$g_{2,H} = 100 - (H-1)\cdot\Delta g$
H+1	$g_{1,H+1} = H\cdot\Delta g = 100$	$g_{2,H+1} = 0$

Obviously, the lower Δg, the higher H and the higher the detail level that can be achieved with the sensitivity analysis.

Once g_1 and g_2 have been fixed, the whole structure of the weighing system (that is the composition of the vector **W**) is derived based upon Eqn.7.12.

In practice, when a strategy for assigning the relative weights p_{m_n} to the criteria belonging to the same group is defined, the complementary variations of g_1 and g_2 correspond to different decision maker's views that can be collected into an Appraisal Matrix, as carried out in the exercise performed in the previous paragraphs.

A good starting standpoint could be the case in which the criteria belonging to the same group are assigned with the same relative importance, that is:

$$(7.34) \qquad p_{m_n} = \frac{g_n}{M_n} \quad ,\forall n, m$$

Note that this approach is the one used for the views from I to VII in Table 7.6: all the criteria respectively belonging to the ECO, ENV and TEC groups (as specified in Table 7.4) were assigned with the same relative weight.

Generally speaking, the sensitivity analysis assessed based upon the above lines is in practice analogous to an appraisal matrix constructed with constant relative weights inside the homogeneous groups.

Due to the fact that a sensitivity exercise performed throughout more than 50 independent concordance analyses would be quite large if represented in a table-format (such as the one required by the appraisal matrix), a graphic output could be more useful in understanding the stability of the final ranked plans.

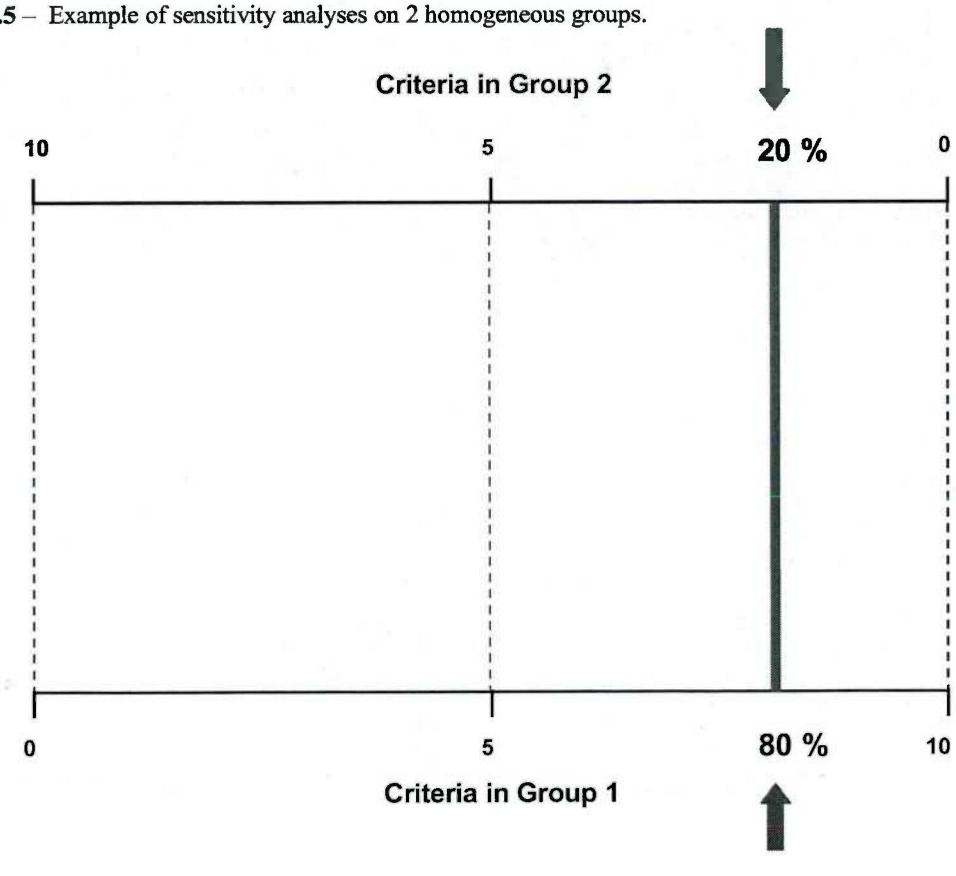
A solution could be to draw a diagram in which the global synthetic index GS_i is plotted against the weight assigned to one of the 2 groups.

This solution is given in **Fig. 7.5**. Upper and lower X-axes are expressed in a complementary scale, as required by Eqn.7.32. Each standpoint on the diagram identifies a vertical segment on which the various synthetic indexes for the case at hand will be plotted.

In the example, the standpoint corresponding to $g_1 = 80\%$ and $g_2 = 20\%$ is put in evidence.

An application of such an analysis is given in **Fig. 7.6**. The criteria presented in Table 7.4 were here clustered into 2 groups, that is:

Fig. 7.5 – Example of sensitivity analyses on 2 homogeneous groups.



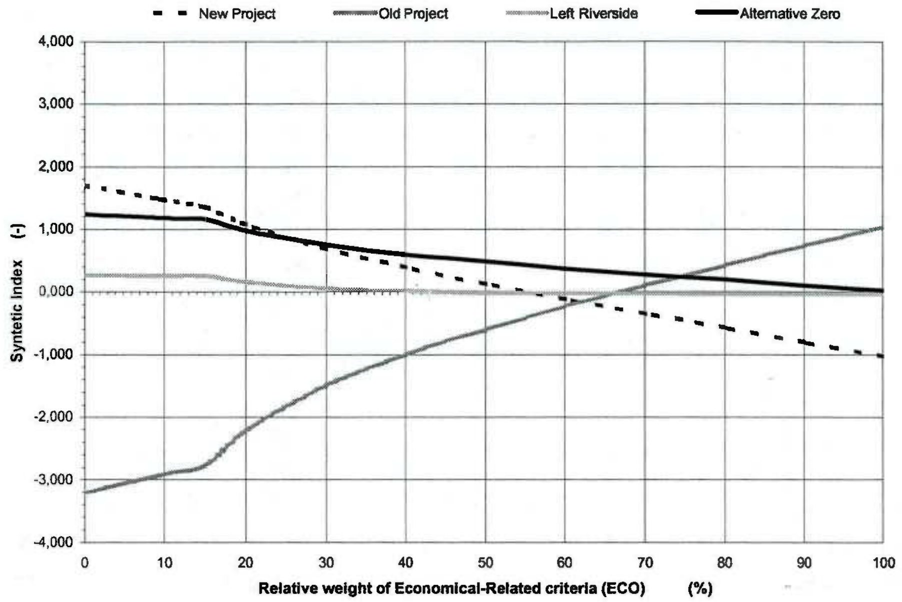


Fig.7.6 – Sensitivity analysis on weighing system which criteria were clustered into two homogeneous groups, that is: ECO = Economical-related criteria; ENV+TEC = Environmental- and Technical –related criteria. All the criteria belonging to the same homogeneous group maintain equal relative weights.

- **ECO**: Economical-related criteria (including only the criteria *EnPro* and *InvPow*);
- **ENV-TEC**: Environmental- and Technical-related criteria (including all the other criteria used for the MEA exercise here presented)

ANALYSIS WITH 3 HOMOGENEOUS GROUPS

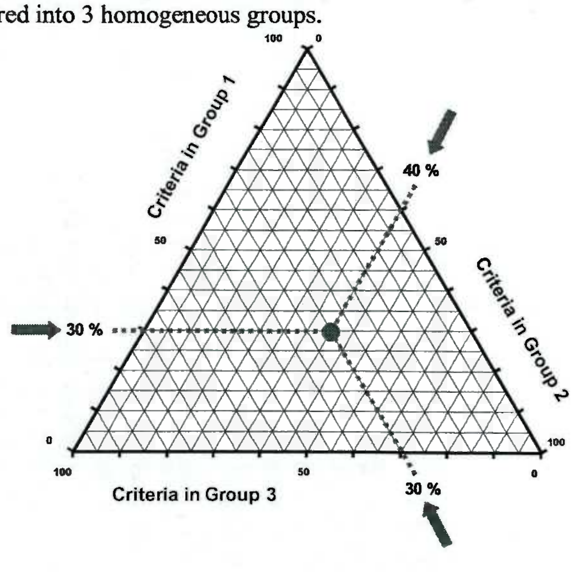
The approach used to perform sensitivity analyses on W previously described can be followed even for criteria clustered into 3 homogeneous groups. The most relevant difference regard the following equations:

$$(7.35) \quad M_1 + M_2 + M_3 = J$$

$$(7.36) \quad g_{1,h} + g_{2,h} + g_{3,g} = 1 \quad (or\ 100\%)$$

In addition the outputs of the sensitivity analyses can be here represented throughout a graphic metaphors by which the final ranking information is mapped on a triangular diagram as the one represented in **Fig. 7.7**.

Fig.7.7 – Triangular diagram used to map the final ranking information provided by the concordance analysis when the criteria are clustered into 3 homogeneous groups.



8 HYPSE USER'S GUIDE

8.1 FOREWORD

HYPSE (acronym of *HYdro Power Systems Evaluations*) is a software package specifically developed for performing multi-criteria evaluation methods in the selection of alternative hydro power system projects.

Implemented in Delphi 5 (by Borland Inc.), it can be run on a PC Windows 95 (or higher) platform and it is formed by a set of procedures that sequentially and interactively carry out all the analysis functions discussed in the previous chapter.

The MEA method performed by *HYPSE* is *concordance analysis*, including sensitivity analysis on weight vectors and even providing powerful graphic metaphors for explaining the obtained outputs.

HYPSE was implemented in a way to be as much user-friendly as possible, in order to assist the user in all the single tasks of the analysis that must be carried out. Even when creating the Impact Matrix **Z**, a template tool is available enabling the user to select his own list of criteria among a set of default issues that are automatically proposed to him.

HYPSE is not a designing tool. It is specifically an evaluation tool. It must be applied only once all the alternative hydro power system projects has been completely designed. The figures to be entered in the impact matrix will be derived by the contents of the preliminary plans or the feasible projects related to each alternative solution at hand.

8.2 INSTALLING AND RUNNING *HYPSE*

HYPSE software package can be installed on every PC having the following basic configuration:

- Pentium processor, or higher;
- 8 Mb RAM;
- 3 Mb of free space on HD;
- Windows 95 operating system, or higher.

The following installation steps are required:

1. close all the applications currently running on the PC;
2. insert the *HYPSE* installation CD-ROM in the PC driver and run the Setup program (SETUP.EXE) found in the main root of the CD;
3. follow all the instructions that will be video-displayed;
4. once the installation is completed, run Windows Explorer to check the presence of all the files that have been provided by Setup.

The suggested configuration structure is that presented in **Fig. 8.1**: the installation procedure automatically creates an "Hypse" directory that should be a subdirectory of the "Program Files" directory. The installation procedure does not automatically create any subdirectory of the Hypse directory. Anyhow, it is recommended to create at least the two subdirectories indicated in Fig. 8.1:

- **Data**: to store the *HYPSE* data files that have the format ***.mca.**
- **Programs Archive**: to store a copy of all the programs running *HYPSE* .

HYPSE package consists of the *HYPSE* application (**HYPSE.EXE**) and a number of associated files. These files include, among others (see always Fig. 8.1):

- 5 ***.dll** files, that must be always stored in the

Fig. 8.1 – Creation example of the *HYPSE* directory and visualisation of the package basic files.

same root of the main application;

- an **HYDROELECTRIC.TXT** file, providing all the parameters for managing the default list of criteria; *this file has not to be directly modified by HYPSE users.*

The installation procedure does not require the restart of the PC.

HYPSE can be then run as follows:

Fig. 8.2 - *HYPSE* icon linked to the application, displayed on the PC desktop

1. by selecting with the mouse button the *HYPSE* label that had been automatically inserted in the Program Files list that can be shown clicking on the Start button of the Windows toolbar;
2. by double-clicking with the mouse button the *HYPSE* icon that can be created by the user on the PC desktop (**Fig. 8.2**);
3. by double-clicking with the mouse button the HYPSE.EXE file shown by Windows Explorer as indicated in Fig. 8.1.

When *HYPSE* is run, the blank front panel shown in **Fig. 8.3** appears. It is composed of three sections:

1. **Menu and Toolbar** sections (upper side);
2. **Criteria and Weights** section (left side);
3. **Projects and Impacts** section (right side).

Sections 2 and 3 provide a set of functions to construct a new impact matrix with its relative weighing system or to load an existing matrix. These functions can be executed selecting in the Menu section the **File/New** or the **File/Open** options, respectively. Both they are the only active options when the program starts.

Near the **Toolbar section**, an edit component enables the user to start entering the name of the particular analysis at hand (**Fig. 8.4**).

The toolbar section provides buttons to execute functions that can be even selected in the Menu section. The following "speed" buttons are available:

Fig. 8.3 – The blank front panel appearing when *HYPSE* starts.

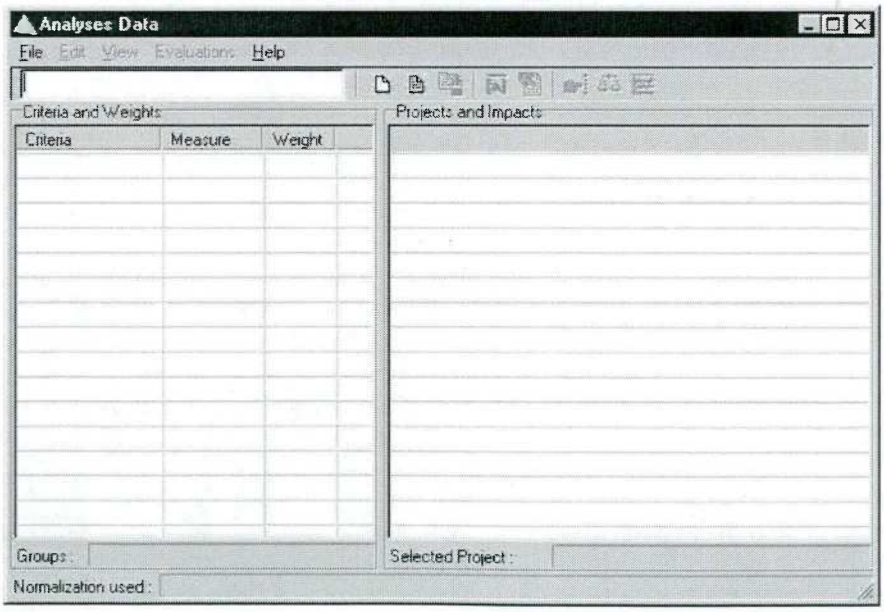
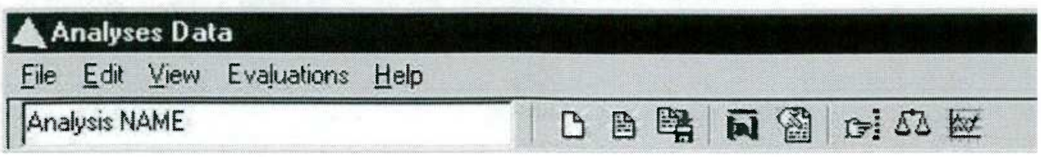
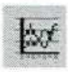


Fig. 8.4 – Menu and Toolbar section with speed buttons



1		Create a new impact matrix - **File/New**
2		Open an existing impact matrix (*.mca) - **File/Open**
3		Save the current impact matrix (*.mca) - **File/Save** (*if the name must be changed select* **File/Save as...**)
4		When selected, it displays the normalised values of the effect figures in the matrix – **View/Normalised Impacts**
5		When selected, it displays the window showing the details of the concordance analysis results; in particular, concordance and discordance matrices together with concordance, discordance and the global synthetic indexes are listed – **View/Index details**
6		Select the type of normalisation procedure and the concordance and discordance indexes that the user wants to consider in the current analysis; the selected indexes are shown in a separate window when the previous button is pressed – **Evaluations/Indexes selection**
7		Set the weighing system values (enter or modify the relative importance of each criterion; cluster the criteria into homogeneous groups when a sensitivity analysis must be performed) – **Evaluations/Weighting system**
8		Perform a sensitivity analysis on the weighing system – **Evaluations/Sensitivity analysis**

8.3 GETTING STARTED

FOREWORD

The basic features of MEA methods have been already deeply discussed in the previous chapter. Here, when running *HYPSE*, the user should always keep in mind that any MEA method is an evaluation process that must be performed throughout three steps of analysis:

1. **Data collection**: Any project (*alternative*) can be seen as a list of quantitative and qualitative attributes defining it as a possible and independent scenario. The values of these attributes must be retrieved from preliminary plans or feasible projects of any alternative at hand. Thus, it is recommended that the designing phase of each project is at an advanced state when the MEA analysis will be performed. *HYPSE*'s user must work in close collaboration with both the project's designer and the final decision-maker. This is why they have to agree together upon the list of attributes (say *criteria*) that must be included into the analysis. The type and the number of criteria deeply influence the final results. This common preliminary task is essential to ensure coherence and correctness to the evaluation process as a whole. All considered, the data collection step implies the definition and the construction of the impact matrix **Z**.
2. **Choosing a way to compare alternatives**: This step can be divided into two tasks: *a)* fixing the relative importance that the decision-makers wishes to assign to each criterion or, if any, to each group of homogeneous criteria; *b)* selecting the indexes that should be used to rank the final preferences representing the final output of the evaluation process.
3. **Interpretation of results**: The final "reading" of the computed indexes could be not immediate and simple. Their interpretation is something subtler than merely com-

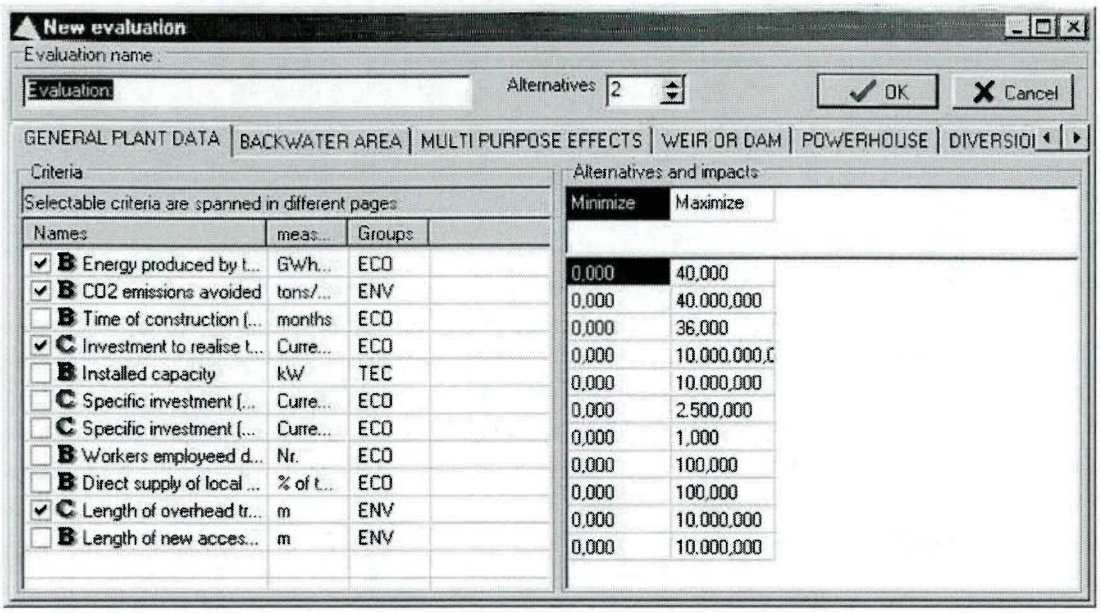
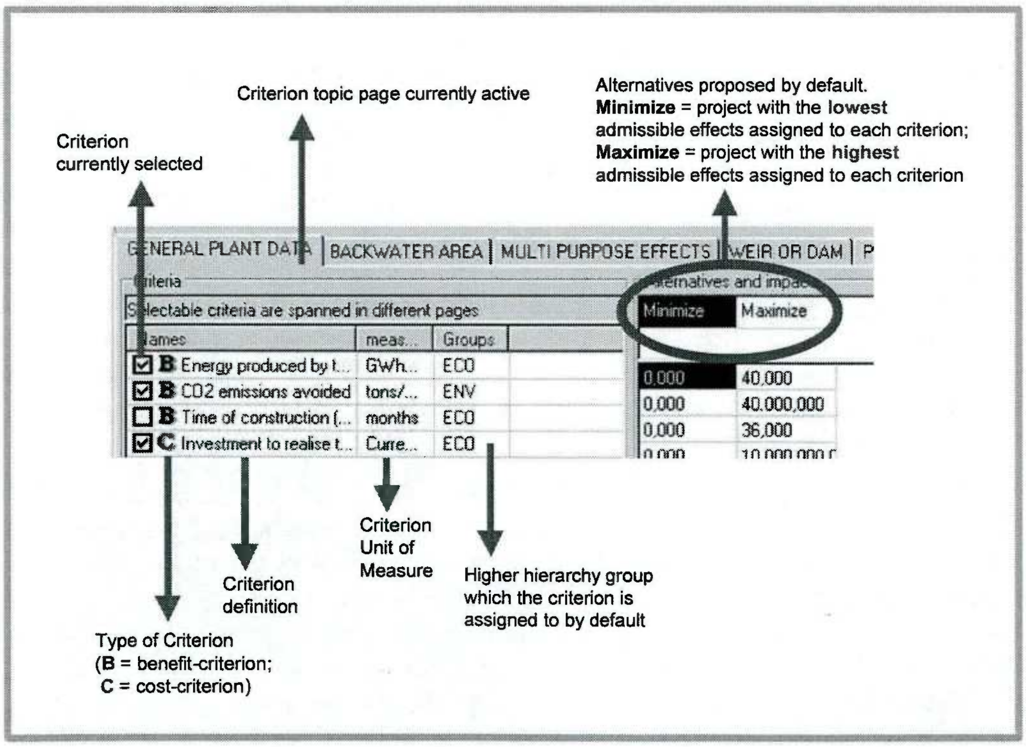


Fig. 8.5 – Assisted environment provided to create a new impact matrix.

pare results, because situations can be complex and exposed to change. Experience and practice in addition to a good knowledge of the analysis tool one has at hands are surely required for this task.

It is important to stress again the need of an interdisciplinary exercise among the three actors of the evaluation process: the decision maker, assisted by both the project designer and the *HYPSE*'s user. And this becomes imperative when sensitivity analyses are performed. In particular, the sensitivity analysis on the composi-

Fig. 8.6 – Details of a criterion topic page in the matrix-building assisted environment



tion of the weighing system can be considered a multiple iteration of a simple Concordance Analysis run, because it provides a way to automatically modify some behaviours in order to observe variations in preferences. It is surely in this tool that *HYPSE* can prove its original and new features, assisting and providing the decision-maker of a graphical representation of an otherwise cryptic mess of output data.

*CONSTRUCTING THE IMPACT MATRIX **Z***

HYPSE provides an assisted environment in order to easily create a new impact matrix **Z**. Once created, it must be saved as ***.mca** file.

The assisted environment consists of a set of tables presenting a list of predefined criteria. The input procedure is called by selecting **File/New** from the Menu section or pressing the related button in the Toolbar section (**Fig. 8.5**).

A window titled "*New evaluation*" is then video-displayed. Firstly, a new name for the evaluation that is going to be considered should be entered in the specific left upper edit mask.

The details for working on the assisted input tables are given in **Fig. 8.6.**

For a better comprehension, the default criteria are grouped into the following 9 homogeneous topics:

1. General plant data;
2. Backwater area;
3. Multi-purpose effects;
4. Weir or dam
5. Powerhouse
6. Diversion section
7. Head race channel/penstock
8. Tailrace channel;
9. Tailwater area.

A specific criterion topic page is selected by clicking its related label in the upper part of the table area. Each topic includes a different number of criteria, dealing with homogeneous aspects that can be derived from the feasible project of each alternative. In total, throughout the 9 topic pages, 61 default criteria are here proposed. To look over the complete list of default criteria, see **Table 8.1**.

Table 8.1 – List and features of the default criteria automatically provided by *HYPSE* when creating a new impact matrix. The information of the following table is stored in the file **Hydrolectric.txt**.

SPECIFICATION OF CRITERIA				DEFAULT PROPERTIES			RANGE	
#	**Label ident.**	**Definition**	**Unit of Measur.**	**Group**	**Benefit criterion**	**Selected**	**Min.**	**Max.**
I	**GENERAL PLANT DATA**							
1	*EnPro*	Energy produced by the plant	*GWh/year*	ECO	Yes	Yes	0	40
2	*EmisAv*	CO_2 emissions avoided	*tons/year*	ENV	Yes	Yes	0	40000
3	*WksCstr*	Time of construction (foreseen)	*months*	ECO	Yes	No	0	36
4	*Inv*	Investment to realise the plant	□	ECO	No	Yes	0	10000000
5	*InstPow*	Installed capacity	*kW*	TEC	Yes	No	0	10000
6	*InvPow*	Specific investment (capacity)	*□/kW*	ECO	No	No	0	2500
7	*InvEne*	Specific investment (energy)	*□/kWh*	ECO	No	No	0	1
8	*WksOpe*	Workers employeed during operation	*#*	ECO	Yes	No	0	100
9	*DirEnSup*	Direct supply of local energy demands on total production	*%*	ECO	Yes	No	0	100
10	*LgtTrLines*	Length of overhead transmission lines	*m*	ENV	No	Yes	0	10000
11	*LgtNwRds*	Length of new access roads to the plant	*m*	ENV	Yes	No	0	10000
II	**BACKWATER AREA**							
12	*BckWVel*	Backwater velocity (mean value in the middle of reach in case of mean water)	*m/s*	ENV	No	Yes	0	5
13	*BckLgt*	Backwater length in case of mean water	*m*	ENV	No	Yes	0	5000
	(continue)							

	(continue)							
14	*BckWRipR*	Length of ripraps and levees in the backwater area: right bank	*m*	ENV	Yes	No	0	1000
15	*BckWRipL*	Length of ripraps and levees in the backwater area: left bank	*m*	ENV	Yes	No	0	1000
16	*LndInund*	Total area newly inundated (ev.for storage creation)/area river bed originally	*%*	ENV	No	Yes	100	500
17	*LngImp*	Length of impervious embankments or levees (per bank)	*m*	ENV	No	No	0	1000
18	*PercWidth*	Percentage increase in low water riverbed width	*%*	ENV	Yes	No	0	400
19	*EmbVeg*	Area of newly created embankment vegetation	*m^2*	ENV	Yes	No	0	10000
20	*ShelArea*	Creation of slow velocity / shellow-water areas	*m^2*	ENV	Yes	No	0	10000
21	*Depth*	Depth in the middle of the backwater area/unimpounded depth	*%*	ENV	Yes	Yes	100	500
22	*BkwLngt*	Total length of backwater/maximum width of backwater	*%*	ENV	Yes	No	0	1000
III	**MULTI PURPOSE EFFECTS**							
23	*Recre*	Recreation	*%*	ENV	Yes	Yes	0	100
24	*FloPRo*	Flood protection (increase in flood return period with respect of the natural situation)	*years*	ENV	Yes	Yes	0	100
25	*Settle*	People settlement	*# (persons)*	ENV	Yes	Yes	0	1000
26	*WatSup*	Water supply (irrigation & drinking)	*l/s*	ENV	Yes	Yes	0	70000
27	*EnvArea*	Creation of adjoining ENV areas	*m^2*	ENV	Yes	Yes	0	10000
28	*AgriArea*	Creation of agricultural areas	*ha*	ENV	Yes	Yes	0	1000
IV	**WEIR OR DAM**							
29	*%SeasTrans*	Percentage of the yearly water volume transferred from wet to dry season	*%*	ENV	Yes	Yes	0	100
30	*%DailyTrans*	Percentage of the daily water vol. transferred from empty to peak hours	*%*	TEC	Yes	Yes	0	100
31	*AncDamhgth*	Heigth of gates and ancillaries over the crest of the dam or weir	*m*	ENV	No	Yes	0	10
32	*DmHgt*	Fixed Dam heigth	*m*	ENV	No	Yes	0	20
33	*BedLoad*	Interruption of bedload transport	*%*	ENV	No	No	0	100
34	*RivCont*	Interrupt.of river continuum inverse to quality of fish bypass system	*%*	ENV	No	Yes	0	100
V	**POWERHOUSE**							
35	*AreaPow*	Area used by the powerhouse	*m^2*	ENV	No	No	0	2000
36	*AreaAdd*	Area used by additional constructions (roads & parking)	*m^2*	ENV	Yes	No	0	10000
37	*NoiEmi*	Noise emission from powerhouse	*dBA*	ENV	No	Yes	0	120
38	*PercUndPow*	Percentage of underground powerhouse	*%*	ENV	Yes	Yes	0	100
VI	**DIVERSION SECTION**							
39	*DivLng*	Diversion length	*m*	ENV	No	Yes	0	5000
40	*WetWid*	Wetted width/width of river bed in case of res. flow	*%*	ENV	No	No	0	100
	(continue)							

	(continue)							
41	*StruReach*	Structural improved reach	%	ENV	Yes	No	0	100
42	*TribEff*	Effect of tributaries	l/s	ENV	Yes	Yes	0	10000
43	*NrWaste*	Number of waste water channels discharging between weir and tailwater outlet in the river	#	ENV	No	No	0	50
44	*ResFlow*	Reserved Flow	l/s	ENV	Yes	Yes	0	10000
45	*SpecRes*	Specific reserved flow	l/s.m	ENV	Yes	Yes	0	100
VII	**HEADRACE CHANNEL/PENSTOCK**							
46	*PercIntPnstH*	Percentage of undergound penstock or channel	%	ENV	Yes	Yes	0	100
47	*HeadEarthCh*	Percentage of earth channels	%	ENV	Yes	No	0	100
48	*HeadStruEmb*	Percentage of structured embankment	%	ENV	Yes	No	0	100
49	*HeadConCh*	Percentage of concrete channels	%	ENV	Yes	No	0	100
50	*HeadEcoFun*	Percentage of ecological function	%	ENV	Yes	Yes	0	100
VIII	**TAILRACE CHANNEL**							
51	*PercIntPnsTt*	Percentage of undergound penstock or channel	%	ENV	Yes	Yes	0	100
52	*HeadEarthCh*	Percentage of earth channels	%	ENV	Yes	No	0	100
53	*HeadStruEmb*	Percentage of structured embankment	%	ENV	Yes	No	0	100
54	*HeadConCh*	Percentage of concrete channels	%	ENV	Yes	No	0	100
55	*HeadEcoFun*	Percentage of ecological function	%	ENV	Yes	Yes	0	100
IX	**TAILWATER AREA**							
56	*TailWRed*	Tailwater velocity reduction (vred/vunred)	%	ENV	No	Yes	0	100
57	*TailWSelRed*	Tailwater water surface elevation reduction	m	ENV	No	Yes	0	5
58	*IncrFlood*	Percentual increase in maximum flood or dam break flow rate or tailwater level	%	ENV	No	No	100	500
59	*PercWidth*	Percent. increase in low water riverbed width	%	ENV	Yes	No	0	100
60	*DpthIncr*	Percentage increase in depth	%	ENV	Yes	No	0	100
61	*RedSlo*	Reduced slope/original slope	%	ENV	Yes	No	0	100

Note that each criterion is even qualified by a short *label identifier* that will substitute its extended definition in the definitive impact matrix. Table 8.1 provides also information on criterion default properties and min/max admissible range values for the related effects.

The criteria are not initially all default-selected by *HYPSE's* assisted environment. To modify the proposed selection, simply click over the tick-boxes displayed on the video left-side in order to select/unselect them.

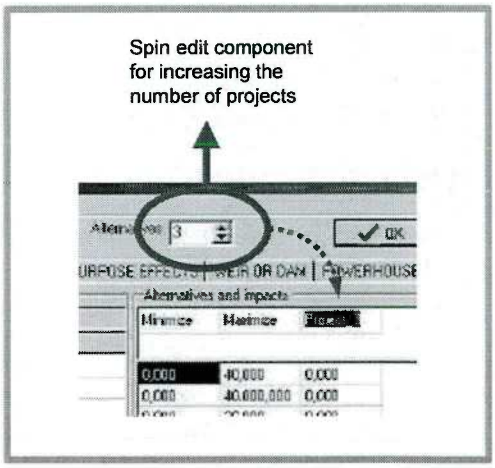
On the right area, the impacts (say effect values) of each alternatives can be entered. *HYPSE* initially provides automatically two default projects, named *Minimize* and *Maximize*, inputting the minimum and maximum values, respectively, of the admissible range shown in Table 8.1.

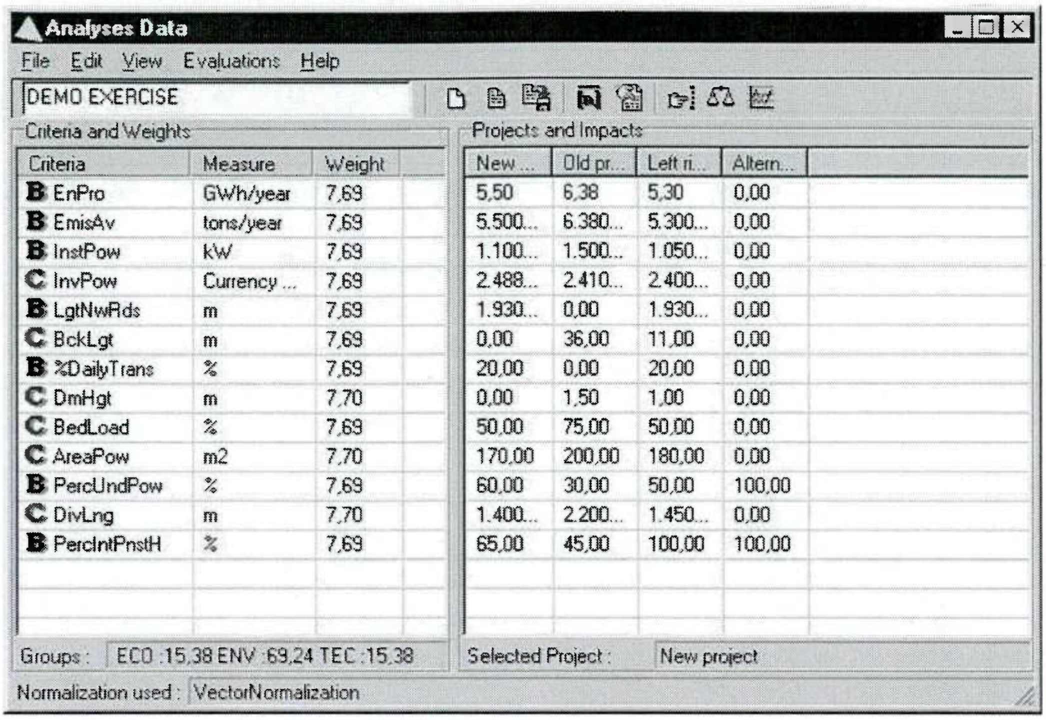
Obviously, to run *HYPSE*, at least **2 projects** must be assessed.

The project number can be increased by clicking the arrows of the spin edit box in the upper side of the table (**Fig. 8.7**). A maximum number of **10 projects** can be selected.

Once having definitively fixed the projects, the content of the cells in the right-side of the

Fig. 8.7 – Changing the project number.





Criteria	Measure	Weight	New ...	Old pr...	Left ri...	Altern...
B EnPro	GWh/year	7,69	5,50	6,38	5,30	0,00
B EmisAv	tons/year	7,69	5.500...	6.380...	5.300...	0,00
B InstPow	kW	7,69	1.100...	1.500...	1.050...	0,00
C InvPow	Currency ...	7,69	2.488...	2.410...	2.400...	0,00
B LgtNwRds	m	7,69	1.930...	0,00	1.930...	0,00
C BckLgt	m	7,69	0,00	36,00	11,00	0,00
B %DailyTrans	%	7,69	20,00	0,00	20,00	0,00
C DmHgt	m	7,70	0,00	1,50	1,00	0,00
C BedLoad	%	7,69	50,00	75,00	50,00	0,00
C AreaPow	m2	7,70	170,00	200,00	180,00	0,00
B PercUndPow	%	7,69	60,00	30,00	50,00	100,00
C DivLng	m	7,70	1.400...	2.200...	1.450...	0,00
B PercIntPnstH	%	7,69	65,00	45,00	100,00	100,00

Fig.8.8 – Impact matrix of the "Demo Exercise" evaluation problem (see also the previous chapter)

table (say, the project names and the effects related to each selected criterion) can be modified selecting the cell by double-clicking on the cell itself.

Attention: *the cells related to criteria currently not selected cannot be entered by new effect values. Then, be previously sure that the interested criterion is selected (say, ticked in the proper left boxed) before trying to modify any impact figure.*

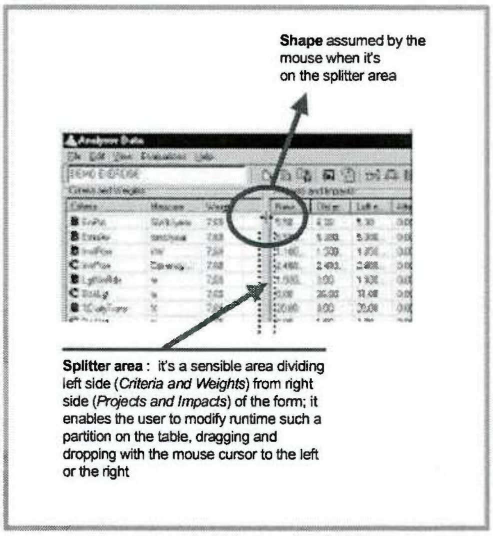
Each criterion is assigned by default to an higher level homogeneous group of criteria, in the terms specified at § 7.4 and § 7.6. This in order to facilitate a further sensitivity analysis on the weighing system. As already said at § 7.2, *HYPSE* proposes the 3 following default groups of criteria:

1. **ECO = Economic-related factors**: related to the monetary and financial aspects of each project;
2. **ENV = Environmental-related factors**: related to the impact that each project is able to induce into the environment in terms of variation of the original and natural living conditions;
3. **TEC = Technical-related factors**: related to the constructive and management aspects that characterise each project.

All considered, for a proper use of this *HYPSE*'s assisted environment, the following steps should be sequentially followed when constructing a new impact matrix:

i. enter a name for the new evaluation at hand;
ii. select the number of projects;
iii. enter a short name for each project selected;
iv. select a topic page (when entering the input assisted procedure the first page *"General*

Fig. 8.9 – Changing table partitions in the impact matrix



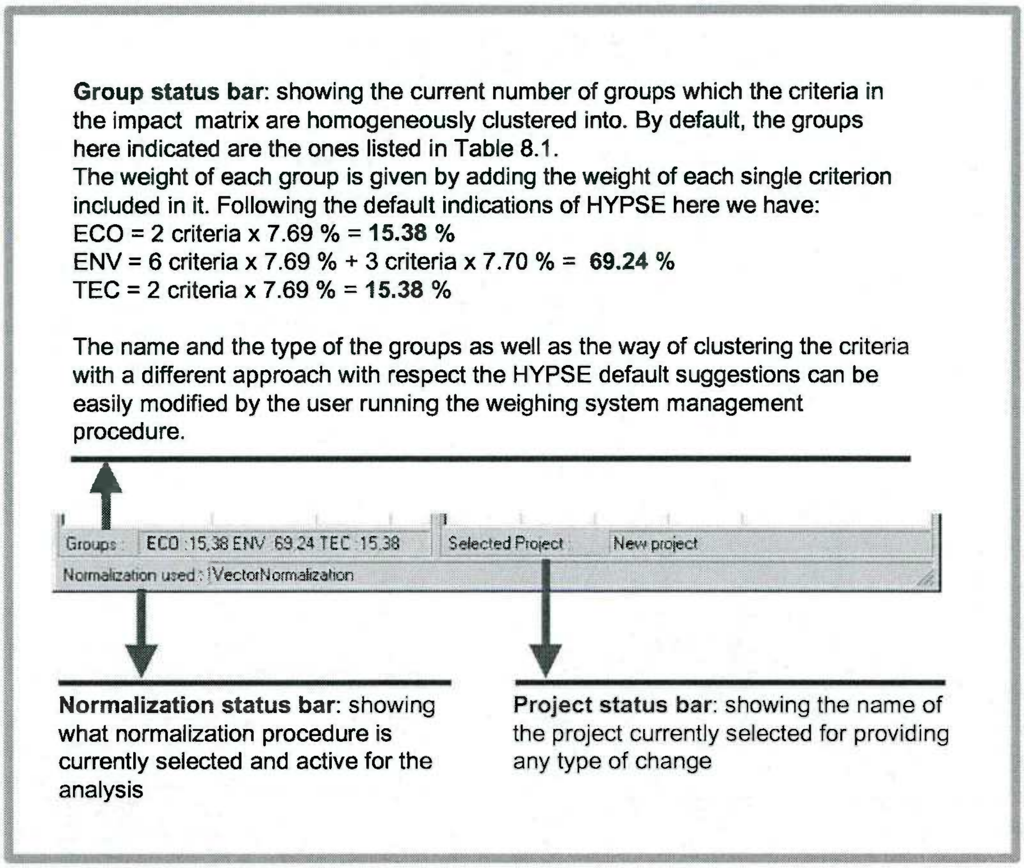


Fig. 8.10 – Bottom status bar of the *HYPSE* impact matrix

plant data" should be active);

v. select or unselect the criteria that must be used in the evaluation analysis;

vi. enter (modifying the proposed figures) the definitive impact values for all the projects and only in correspondence of the selected criteria;

vii. repeat the steps from **iv** to **vi** for all the 9 topic pages proposed by *HYPSE.*

Attention: *when this assisted environment is running, the user cannot modify any parameter that specifies a default criterion (such as its extended definition, its type B or C, its unit of measure and the higher group it belongs to). In addition, the user cannot add an its own criterion in this section. Any relevant change the user wants to introduce must be carried out in the following section, working directly on the definitive impact matrix.*

When all the wished criteria has been selected and entered with their relative impact values, the definitive new impact matrix **Z** will be created pressing the right upper button "OK" of the current window.

☞ **Important**: When a new user's criterion has to be introduced into the analysis (say, not included in the *HYPSE*'s default list), a dummy criterion must be added when running the matrix construction assisted environment. It can be selected among minor criteria presented in the list but not used in the analysis at hand. This dummy criterion will be completely modified in the following working section, using the procedures proposed for managing an already existing impact matrix.

MANAGING THE IMPACT MATRIX ***Z***

Matrix format - When the criteria listed in Table 7.4 and the impact values (Table 7.5) of the projects taken as example to discuss the MEA method in the previous chapter are selected and entered running the above assisted procedure, the impact matrix shown by **Fig. 8.8** is constructed and displayed on the video.

So this is a (13-criteria) x (4-projects) impact matrix.

Note that the previous section didn't deal with anything related to the weighing system. Here we find a weight-vector with all the crite-

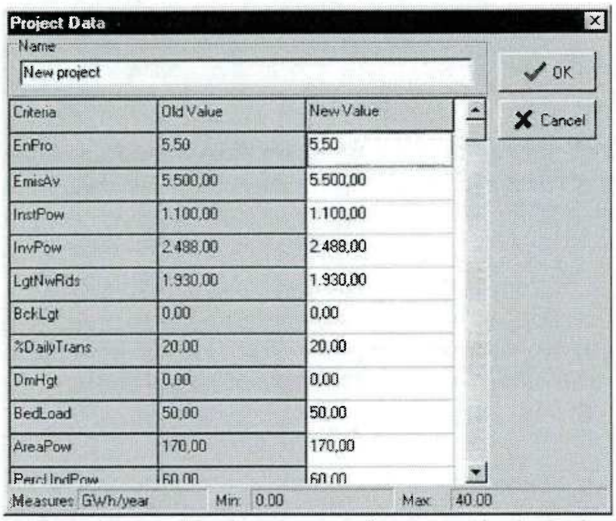


Fig. 8.11 – Edit tool to provide changes to project properties in the impact matrix

ria automatically set up to the same value:
. In other words
importance was given by default to all the s -
. The values in such a vector o -
real numbers
is essential that their sum is . So the round-

in the least significant decimal digit (in this case
e
sults of the round-process depends on the nu -

in the current analysis (see below). This default
1.Equal
listed in the priority matrix of Table 7.6.

main parameters that must be considered during
Projects and Impact
, all the effects are clearly displayed with

column. The width of the columns can be mod -

the methods commonly used in classic sprea -

cell right-border). Even left and right side part -

can be mutually resized runtime using the
Fig. 8.9

On the bottom of the impact matrix window

on the details of the analysis currently assessed
Fig. 8.10

Before performing MEA calculations, enables the user to provide some

input data to the needs of the analysis. Such a -

1. Changes on the properties of each single
;
cr -
;
weighing

.

- Projects can
m
ber (increased or decreased). In order to provide

selected: click with the mouse left button the

of the impact matrix. This name will then a -

At this point select the p
erties...
alternative, simply press the ________________)
Fig.

.

ones displayed into the edit cells with white co -

Only one project at a time can be modified.

the OK-button to leave this edit tool.

project, in this section the user can add or delete
Edit/Projects/Add
Edit/Projects/Delete
respectively (in alternative, press again the ____
mouse button

When a new project is added, all its effect

must be successively changed calling the above

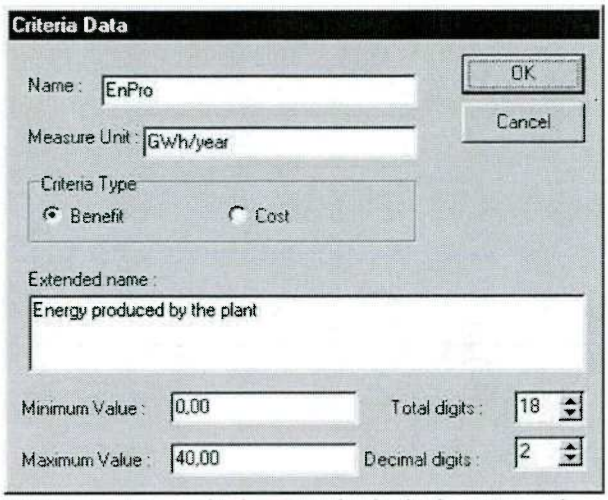


Fig. 8.12 – Edit tool to provide changes to criteria properties in the impact matrix

project edit procedure.

When a project is going to be deleted, it must be previously selected clicking its relative button name on the top of the matrix right side. Before deleting any project, always check the current selection: the destroyed projects cannot be recovered. They should be re-edit manually entirely.

☞ **Important**: Note that in the previous matrix-building assisted environment projects can be **only added**, **not deleted.** If the user, just for mistake, has added one or more undesired projects, he has to delete them here, working directly managing the final impact matrix form.

Changing criterion properties - Also in the case of criteria, only one criterion at a time can be changed. The criterion edit form **(Fig. 8.12)** can be called by clicking with the left button mouse on the criterion row that must be changed and then selecting **Edit/Criteria Properties...** from the top Menu bar (or simply by *double-clicking on the same criterion row* itself). Again, the criterion properties that can be changed are the ones displayed into the edit cells with white colour background. Once all the changes have been provided, press the OK-button to leave this edit tool.

The contents that can be modified regard the properties listed in Table 8.1.

In addition there is here the possibility of modifying the *format* by which the effect (in terms of figure) related to each criterion is displayed inside the matrix. A string of the form **"-d.ddd.ddd.ddd,dddddd..."** is usually applied: it includes thousand and decimal separators.

Attention: *For all formats, the actual characters used as decimal and thousand separators are initialised from the statements in the International section of the Windows Control Panel.*

Two parameters are available to the user for formatting criterion effect-values inside the impact matrix (lower right side of the edit window):

- *Total digits*: the total number of digits used by *HYPSE* to display the figure; the default value is 18, corresponding to the maximum precision of representation; a lower precision can be selected, according to the type of data at hand; if the number of digits to the left of the decimal point is greater than the specified precision, the resulting value will use scientific format.
- *Decimal digits*: the number of digits that satisfies the decimal precision for a specific criterion; the default number is 2; a maximum number of 7 digits can be selected.

The *Total* and *Decimal digits* parameters together control how each single effect value is formatted into a string. Some examples are given in **Table 8.2.**

☞ **Important**: When a user wants to add a new own criterion, not listed in Table 8.1, he has to work on this criterion edit tool to provide all the information required to specify the properties of the new criterion itself. It must be remembered that in order to perform such a task, the user must have previously added (in the matrix-building assisted environment) a dummy criterion, to be selected among the ones of the *HYPSE* default list that surely will not be used within the exercise at hand. *Differently from projects, when managing an impact matrix cri-*

Number	Total digits	Decimal digits	Displayed Format
12345,6789	*18*	*7*	**12.345,6789**
	18	*2*	**12.345,68**
	18	*0*	**12.346**
	8	*7*	**12.345,6790000**
	5	*5*	**12.346,00000**
	4	*5*	**1,235E4**
	3	*5*	**1,23E4**

Table 8.2 – Examples of how the combinations of *Total* and *Decimal digits* parameters condition the displayed format of a number inside the *HYPSE* impact matrix (here the followings separators are supposed to have been set up in the International section of the Windows Control Panel: (.) thousand separator; (,) decimal separator)

teria can be neither added nor deleted from the list built by the assisted environment. The need of changing the number of criteria necessarily requires the construction of a new impact matrix. If a user doesn't want to consider temporarily one specific criterion, can set its relative importance to nil (say, weight value equal to zero).

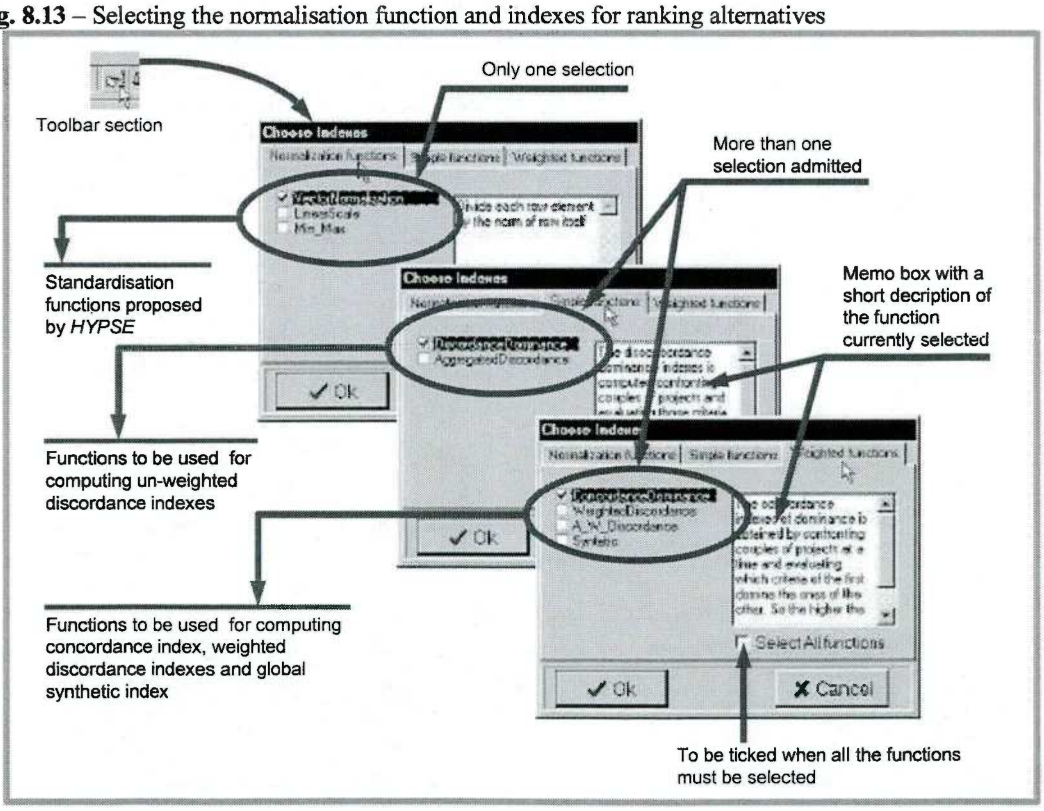
Setting computation indexes - *HYPSE* can be firstly run considering all the criteria with the same importance (analysing the so called **Equal** view in the priority matrix of Table 7.6). The way of changing values in the weighing system will be discussed below in a next paragraph.

Before performing any concordance computation, a set of indexes must be selected. Even if some indexes are proposed as default, this selection is recommended to give consistency and completeness to the computations and to be aware of the final results.

We are referring to the selection of:

1. the method for the **standardisation** of the

Fig. 8.13 – Selecting the normalisation function and indexes for ranking alternatives



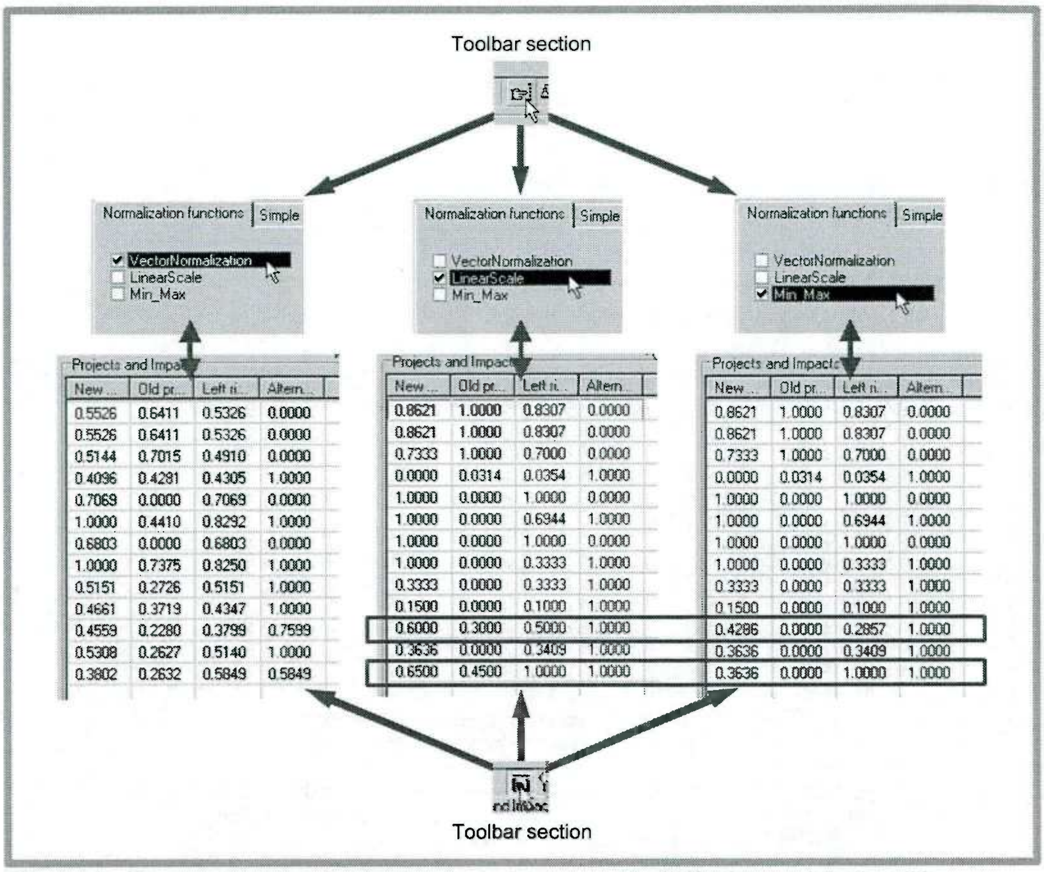


Fig. 8.14 – Viewing the normalised values in the impact matrix (Effectiveness Matrixes **R**).

input data inside the impact matrix;

2. the final <u>**concordance and dominance indexes**</u> together with the <u>**global synthetic index**</u>, by which the final rankings among alternatives can be analysed; in particular this selection consider separately the indexes computed <u>*using*</u> and <u>*not using*</u> the values of the weighing system (say, calculated throughout <u>*simple functions*</u> and <u>*weighted functions*</u>, respectively).

The index selection procedure is called selecting **Evaluations/Indexes selection...** from the Menu section above the impact matrix, or simply clicking the relative speed button from the Toolbar section (see § 8.2 and **Fig. 8.13**).

The default normalisation procedure proposed by *HYPSE* is the one using the *Vector Normalisation* formula, described by Eqn.7.4. To modify this selection, click with the mouse button on one of the other two tick boxes:

- *LinearScale*, performing a linear scale transformation, according to Eqn.7.5;
- *Min_Max*, performing a min-max transformation, according to Eqn.7.6.

Obviously, only **one selection** is here admitted.

In order to view the results of the selected standardisation procedure, select **View / Normalised Impacts** from the main Menu section or press the fourth speed button in the Toolbar section (**Fig. 8.14**). This will let the effectiveness matrix R to be displayed on the screen in place of the impact matrix **Z**. The latter can be recalled un-selecting the procedure or repressing the same speed button of the Toolbar section.

The decimal values are represented by default throughout a number that is a fixed formatted string with 4 decimal digits.

The examples proposed in Fig. 8.14 consider all the 3 standardisation cases. The third one (obtained with the Min_Max function) corresponds to the effectiveness matrix that had been introduced by Table 7.7. Here note that, a part from the two rows underlined by the red boxes (corresponding to the criteria named *PercUnd-Pow* and *PercIntPnstH*), the linear scale transformation and the Min_Max function produce for many criteria the same standardised effect values. That's because in the original impact

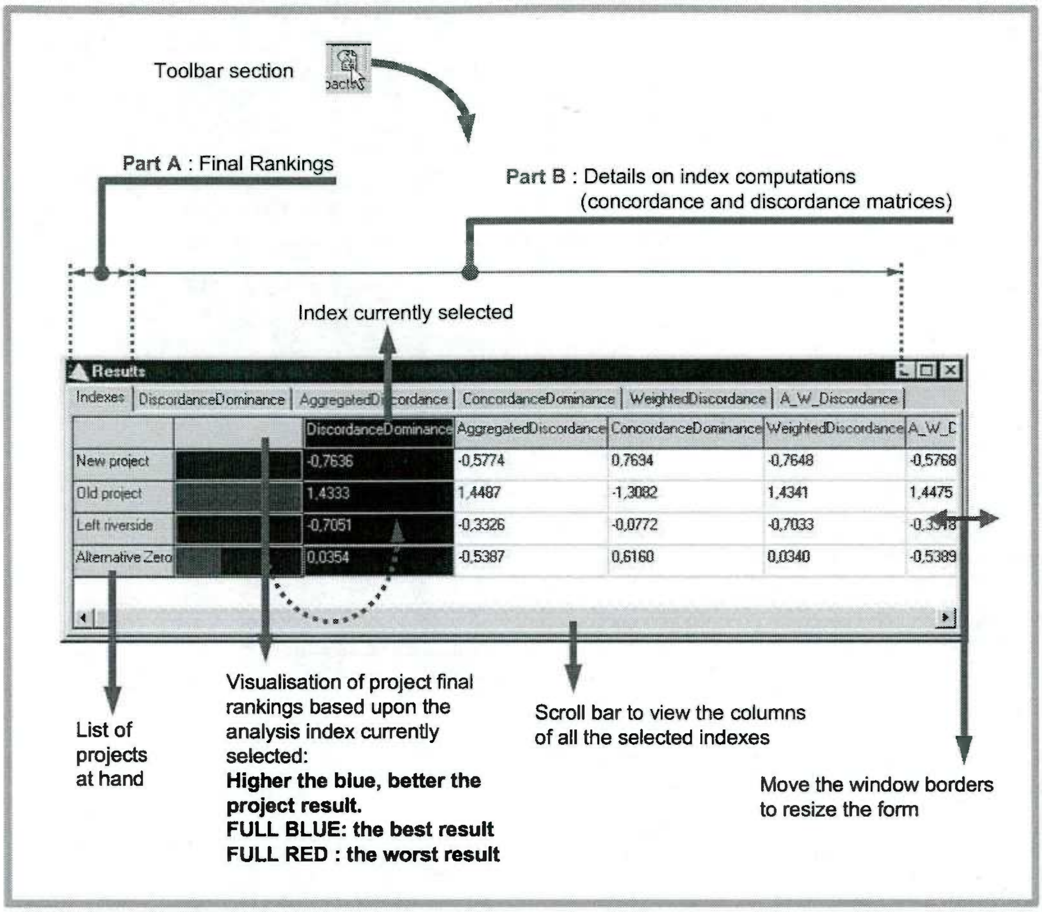


Fig. 8.15 - *HYPSE* Results form

matrix in the most part of criteria there is an effect with at least a zero-value. And this causes the Eqns.7.4 and 7.6 to produce the same result. No zero value is instead present in the rows of the *PercUndPow* and *PercIntPnstH* criteria.

For weighted and unweighted concordance/discordance indexes (see § 7.5 and § 7.5) a multi-selection is admitted.

Analysing final rankings among alternatives

HYPSE performs concordance calculations continuously, each time that whatever type of change is provided into the impact matrix or in the selection of the computational indexes.

The final ranking results can be on-line displayed in an independent form.

In order to view this output-form, select **View/Indexes Details** from the main Menu section or press the fifth speed button in the Toolbar section **(Fig. 8.15)**. When the new window appears on the screen, it is convenient to move and resize it in order to be able to look at the impact matrix and results forms simultaneously. This according to the type and size of screen at hand.

The results form includes a set of columns and tables, presenting the scores achieved by each project. Only the indexes selected throughout the procedure discussed at the previous paragraph are here displayed.

The information provided by the form is divided into 2 parts:

- **Part A**: presenting the final project rankings based upon the selected concordance and discordance indexes; a column is assigned to each index; according to what discussed at § 7.5, when all the computational indexes have been previously selected running the **Evaluations/Indexes selection…** procedure from the Menu section, 6 output columns are here displayed: **1** for the concordance index; **4** for the discordance indexes and **1** the global synthetic index. In practice, the example presented in Fig. 8.15 is analogous (not equal, owing to the different weighing systems) to the summary Table 7.14, presented in the previous chapter. For a better compre-

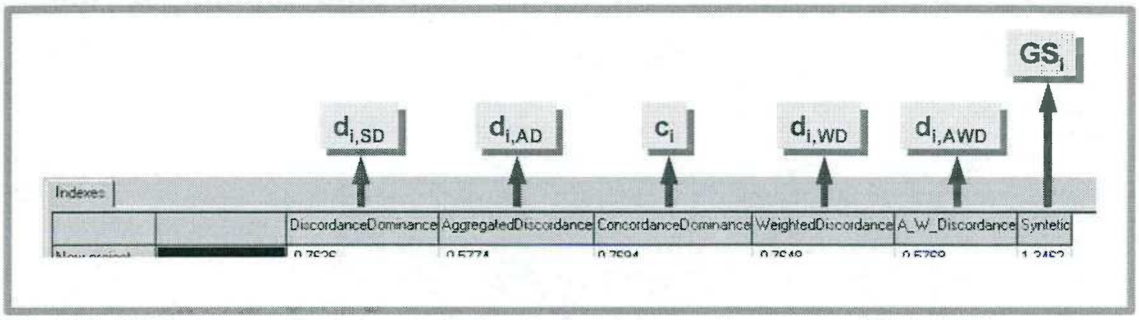


Fig. 8.16 - *HYPSE* computation indexes in the Results form (see even the example of Table 7.14)

hension of the correspondences between *HYPSE* indexes and the symbols there used, see **Fig. 8.16.**

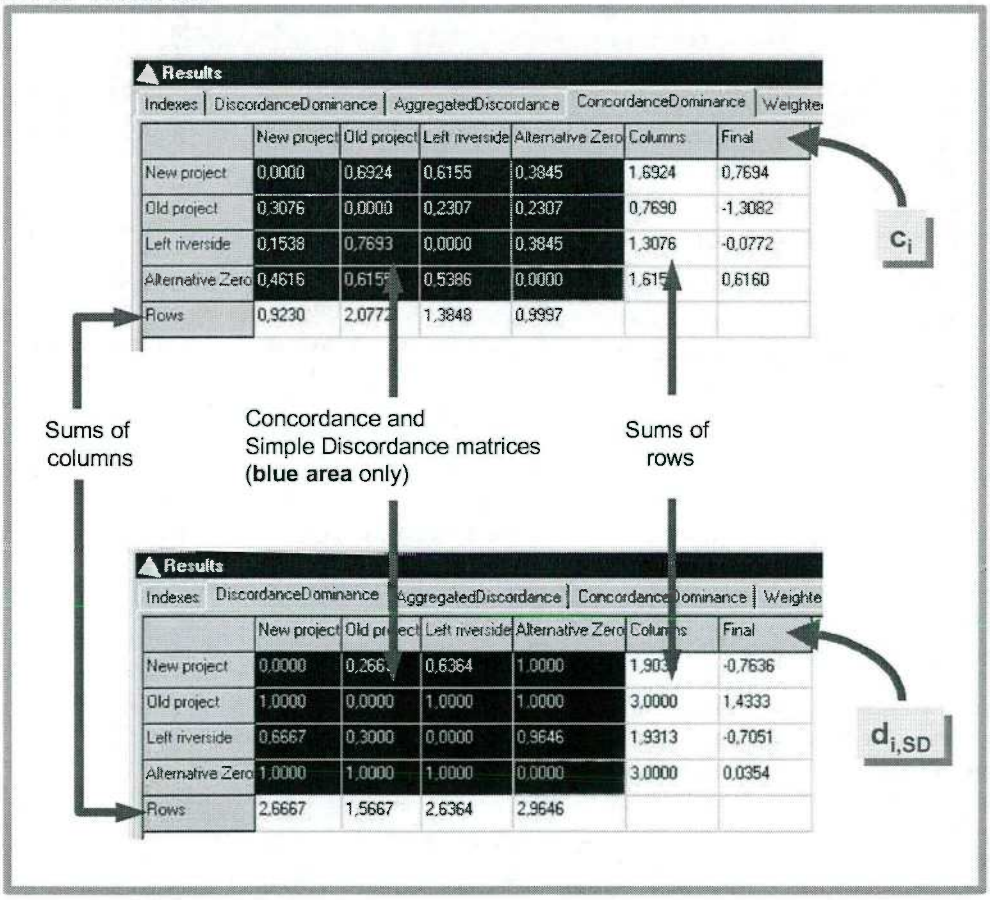
- **Part B**: presenting more detailed information on the computations of each selected index; in particular, concordance and discordance matrices are here proposed **(Fig. 8.17)**. All the figures are given with a fixed 4-digit decimal precision.

In Part A the index ranking is even proposed in a graphic way throughout a list of red and blue bar histograms (second column); higher the blue, better the project performance.

Attention: *the output histograms are related to the index currently selected; so, before considering any graphic result, be aware of selecting the desired index by clicking its related column with the mouse button;*

In the example of Fig. 8.15, the simple discordance concordance index ($d_{i,SD}$) has been se-

Fig. 8.17 – Example of how concordance and simple discordance matrixes are displayed on *HYPSE* Results form



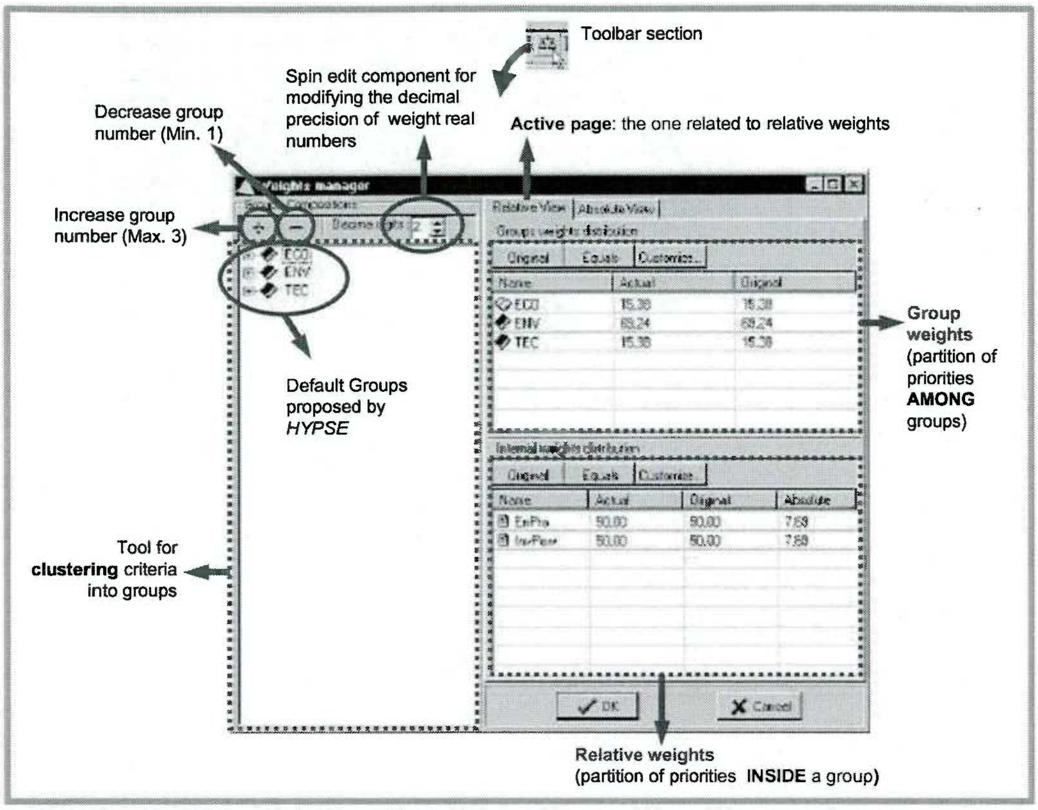


Fig. 8.18 – The edit weight manager form

lected: note that in such a case the best result is the one having the lowest (negative) value, whilst the worst is the "*Old Project*" solution with the highest (positive) index value.

8.4 MANAGING THE WEIGHING SYSTEM

FOREWORD

The general properties of a weighing system of a MEA problem have been discussed in § 7.4 and in § 7.6. Formally, this is a vector of **real numbers** defining criterion priorities.

We saw that when starting a new problem *HYPSE* creates a vector with priorities equally partitioned among all the criteria.

But normally it is necessary to modify such a situation because:

- the user wants to set up *his own priority standpoint* to run a new *HYPSE* single computation;
- a *priority matrix* must be constructed with a *S* finite number of views; *HYPSE* will then be run *S* times (one run per view) in order to construct an appraisal matrix with a set of different results;
- a *sensitivity analysis* to test the stability of the final results with respect to the composition of the weighing system must be performed (we will see that in such a case *HYPSE* computations will be automatically iterated up to 100^2 times).

Changes to be provided to a weighing system can regard:

1. the values of **absolute weights**;
2. the values of **group weights**;
3. the partition of weights inside a group (**relative weights**).

In order to enable the user to perform the above changes, *HYPSE* must provide an edit tool able to:

- cluster criteria into homogeneous groups, to be defined by the user himself (three groups are proposed by default);
- handle the decimal precision of weight real-numbers without creating any inconsistency round problem.

THE WEIGHTS MANAGER TOOL

The weights manager edit tool is called selecting **Evaluations/Weighting system...** from the main Menu section or simply pressing the relative speed button in the Toolbar section **(Fig. 8.18)**.

The main form is composed of two parts:

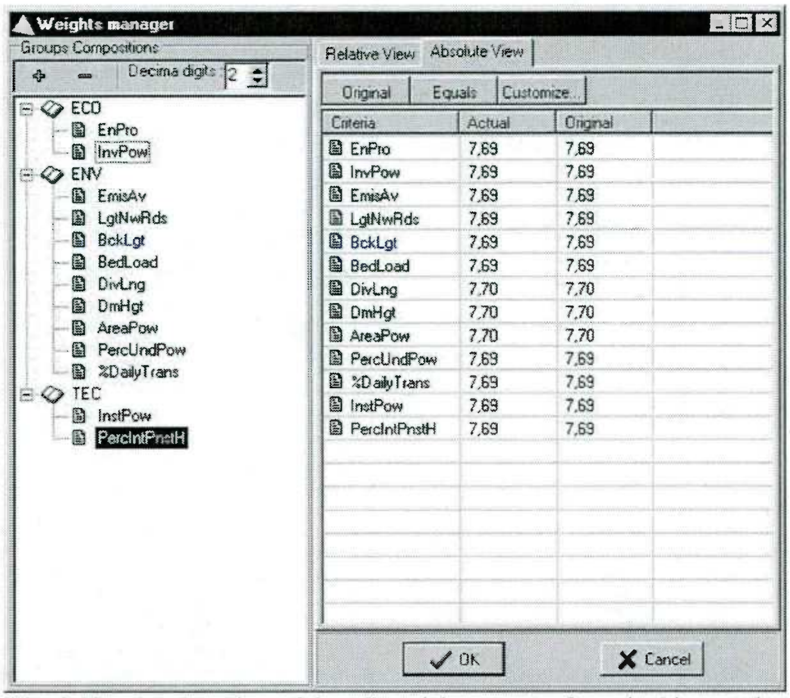


Fig. 8.19 – Another view of the edit weight manager form: in this case the *Absolute view* page is selected in the right side of the form.

a) the left side part (*Groups composition* box), with the tool for defining higher-level weight groups and for clustering the criteria at hand into the defined groups;
b) the right side part, for entering weight figures.

The right side part offers the possibility of selecting two distinct pages:

- **Relative view**, for inputting weight values starting from the division of criteria into groups; in such a case there are two input steps: a) entering *group weights* (working in the upper right side part of the form, *Groups weights distribution* box); b) entering the *relative weights* inside a group (working in the lower right side part of the form, *Internal weights distribution* box). Absolute weights will be then computed by *HYPSE* as a consequence of these two inputs.
- **Absolute view**, for inputting directly the absolute weight of each criterion, independently on the way they were clustered into groups. Group weights and relative weights inside each group (if any) will be then computed by *HYPSE* as a consequence of this absolute input together with the method followed in forming the groups.

In the example presented in Fig. 8.18, the *Relative view* is the selected active page. Note the two right parts indicated by the red dotted boxes: they permit the independent inputs of group and relative weights.

When the *Absolute view* page is selected, the edit tool turns on the form shown in **Fig. 8.19**.

HOW TO CLUSTER CRITERIA INTO GROUPS

The tool for managing criteria into groups is a typical tree component of the MS Windows platform. It looks as a set of folders (from 1 to 3) which contents can be viewed by clicking with the mouse button on the box with the "+" symbol positioned at left of the folder name. Each folder is an higher-level criterion group. As stated above, *HYPSE* provides 3 default groups (ECO, ENV and TEC). Criteria are grouped into them according to the clustering properties specified in Table 8.1. When a group-folder is open, its content appears as shown on the left part of Fig. 8.19.

The user can modify one (or more) default folder-name by double-clicking with the mouse button on the name itself to select the name label on the edit mode; once selected, enter the new name and press "enter" to accept it.

The example proposed by Fig. 8.19 is the automatic result provided by the *HYPSE* matrix-builder assisted environment. Note that this situation is different from the demo-problem

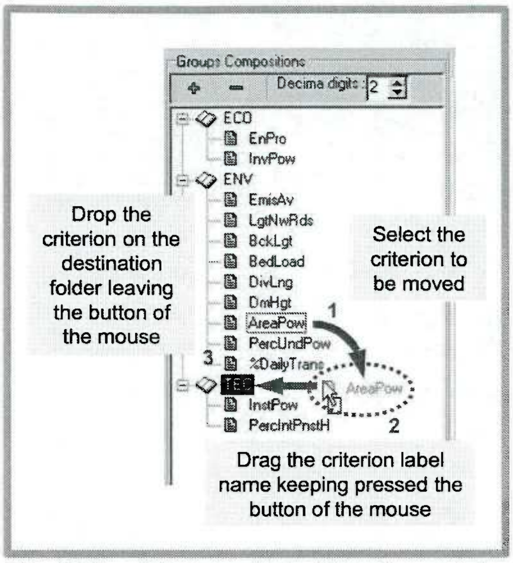


Fig. 8.20 – Moving criteria (dragging and dropping) between groups

specifications given in Table 7.4. In fact, there we had:

- *ECO*: 2 criteria (the same number of Fig. 8.19);
- *ENV*: 5 criteria (4 criteria less than in Fig. 8.19);
- *TEC*: 6 criteria (4 criteria more than in Fig. 8.19);

This means that to solve our demo-problem with the same specifications given in the previous chapter, we have to move 4 criteria from the ENV folder to the TEC folder. This task can be performed following the action steps given in **Fig. 8.20.**

Only one criterion per time can be moved.

For reducing the number of groups (for example when a 2 weight-group sensitivity analysis must be performed), take present that an existing folder cannot be deleted if it still includes some criteria. So, they must be previously moved into another folder, before destroying the father-folder.

The short-name of criteria cannot be modified working on this group tool manager. For performing this task see pag. 83.

HOW TO ENTER WEIGHT FIGURES

Both *Relative view* and *Absolute view* pages enable the user to look at the present weighing system values and to modify them. They both display tables always including 2 columns (3 in the case of the *Internal Weight distribution* box, even providing a 3rd column with the absolute weight values; see Fig. 8.18) presenting current

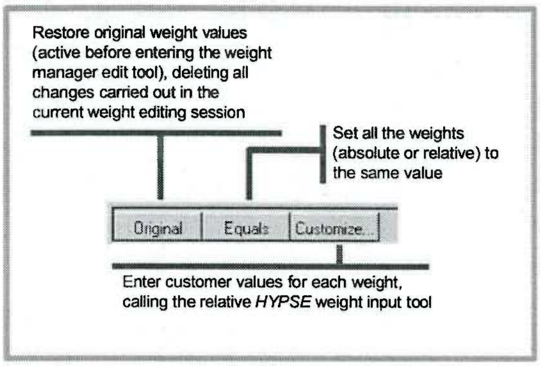


Fig. 8.21 – Weight value command buttons

(say, actual) and original weighing system content. The former refers to the changes the user is going to provide, starting since he entered the weight manager tool, whilst the latter refers to the state of the weighing system prior entering the weight manager tool. Each edit box has on its top 3 working buttons performing the functions described in **Fig. 8.21.**

When the user wants to customise his own values, the button **Customize...** must be clicked. This calls the special *HYPSE* weight editing tool shown in **Fig. 8.22.**

In order to avoid any round problem in managing weight-value real numbers, weight figures can **never** be entered directly inputting digits throughout the keyboard. This *HYPSE edit tool uses some track bars to input weight values.*

The edit form presented in Fig. 8.22 (named "**Weights control**") is called when the button **Customize...** is clicked from the "*Absolute view*" page. So it includes the complete list of all the criteria used in the analyses at hand. Differently, when the form is called from the "*Groups weights distribution*" box or from the "*Internal weights distribution*" box, the list of the groups or the list of the criteria within each selected group is shown, respectively.

Whatever the case, note that the edit form is divided into two parts:

- a right side part, with a box containing as many track bars, as the number of criteria is (or as the number of groups is); just below each track bar, the name of the criterion (or of the group) is displayed together with the real number currently representing its relative importance (that is its weight); a central scroll bar, enables the user to move along the criteria list;
- a left side part, with a box named "*Excedence view*", to indicate positive (*surplus*) or negative (*shortage*) variations of the

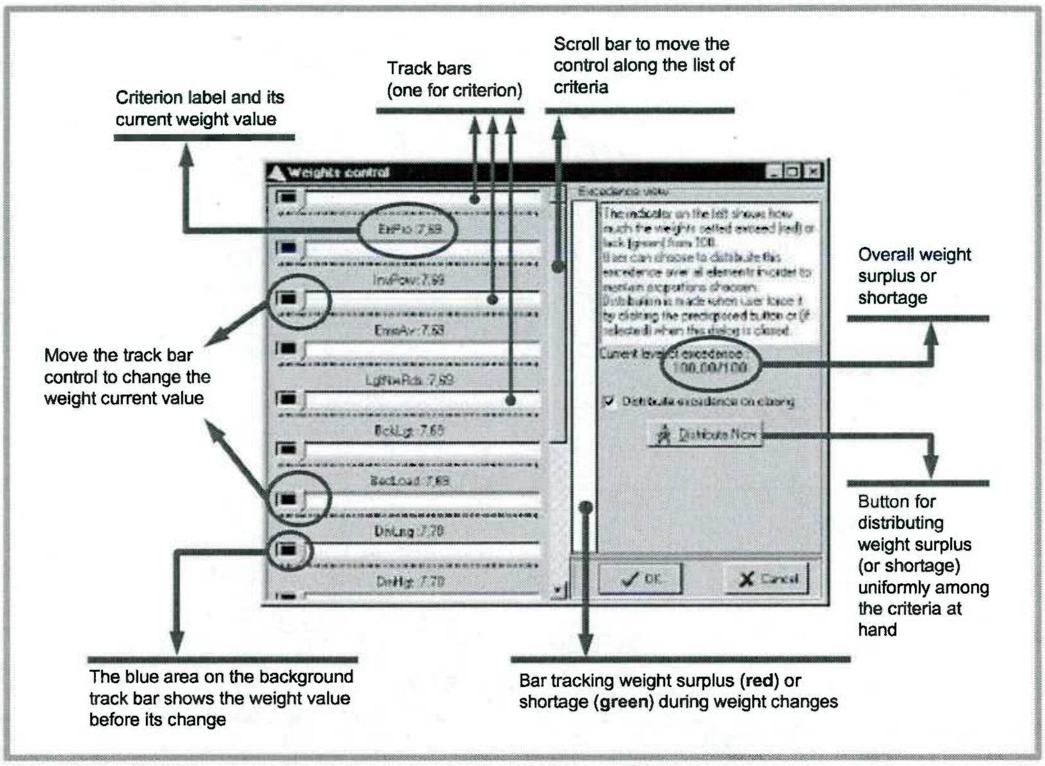


Fig. 8.22 - *HYPSE* weight editing tool (called by the buttons **Customize...**)

total weight amount with respect to the global target value of 100; such variations occur every time a weight of a single criterion (or group) is modified moving left (shortage) or moving right (surplus) the control virtual cursor of the above said track bars.

Surplus and shortage in the sum of criterion weights is even presented in a graphical way: a central gauge (vertical bar) display a **red** or **green** bar on white background when a surplus or a shortage is respectively detected by *HYPSE*. The quantitative level of surplus or shortage is displayed on a separate string as well (**Fig. 8.23**).

Any positive or negative variation with respect to the expected weight sum of 100 has to be necessarily eliminated before exiting this "*Weights control*" form. So surplus or shortage must be redistributed among all criteria. This distribution is carried out when the user forces it by clicking with the mouse on the button "Distribute now" or automatically by *HYPSE* when closing this edit form (only if the relative check box "*Distribute excedence on closing*" is selected).

Anyhow, if a sum not exactly equal to 100 is detected, a dialog message box advises the user to check again the weight assessment at hand. Dealing with real number, the precision depends on the number of decimal digits are here used to represent criterion weights. By default, *HYPSE* works with 2 digits only (see the spin edit component on the upper left part of the weights manager tool).

When changing weight values with the track bar components, there could be the necessity of providing very short movements with the mouse to get a 2-decimal precision. To make this task easier, use the keyboard left and right arrows to get the expected precision.

8.5 Performing Sensitivity Analysis

General Aspects

The general aspects of sensitivity analysis on the weighing system compositions have been treated in § 7.6. *HYPSE* enables the user to perform sensitivity analysis based upon those concepts, providing tools for carrying out calculations on 2 and 3 homogeneous groups of criteria.

The sensitivity analysis procedure is called selecting **Evaluations/Sensitivity Analysis...** from the main Menu section or simply pressing the relative speed button in the Toolbar section (**Fig. 8.24**).

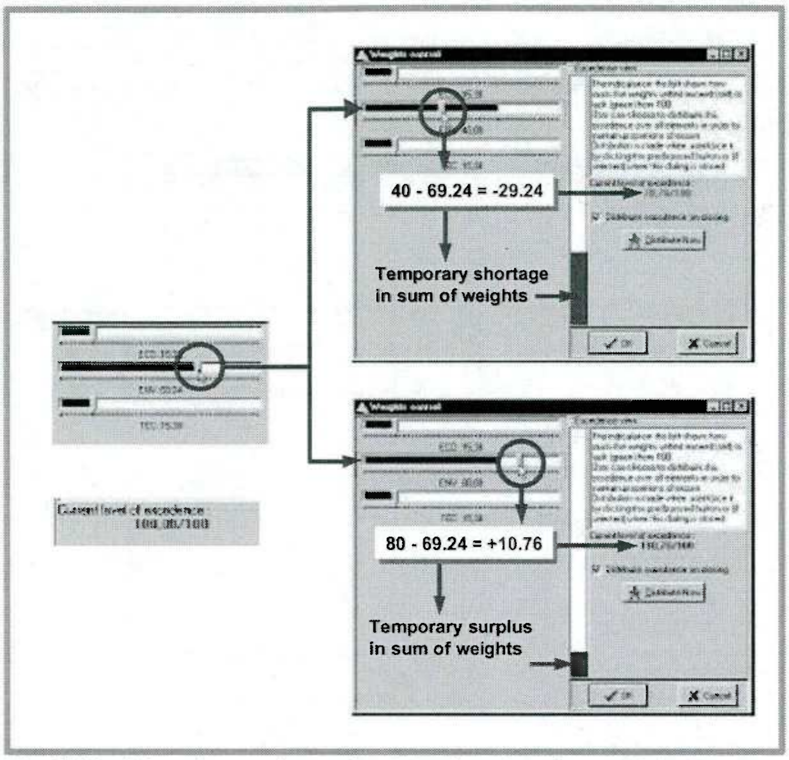
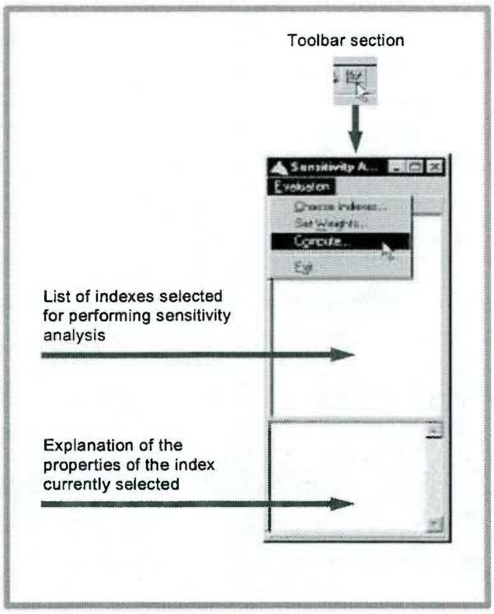


Fig. 8.23 – Managing surplus or shortage when changing weight values

The form that is then displayed on the screen is a sort of "*analysis inspector*" composed of two parts:

a) an upper part, with a memo box in which the indexes selected for the analysis will be displayed;

Fig. 8.24 – Starting form for sensitivity analysis



b) a lower part, with a second memo box in which the description of one of the selected indexes included in the list at the previous point will be presented for user's commodity.

This form is an independent window that should be display together with the other forms that are going to be presented by this procedure. The user can move the form on a video corner – based upon his earlier convenience – so that some space is left for the other tools on which he is going to work.

This main form provides a Menu section with a single option only: **Evaluation.** On its hand, this option includes 3 commands:

1. **Choose indexes...;**
2. **Set weights...;**
3. **Compute....**

The actual sensitivity analysis computations are performed only by the 3rd command **Evaluation/Compute....** But before performing any calculation, the general computation background must be assessed in terms of:

a) selection of the indexes on which we want to carry out the analysis (**Evaluation/Choose Indexes...**);
b) clustering all the criteria at hand into 2 or 3 homogeneous groups (**Evaluation/Set Weights...**).

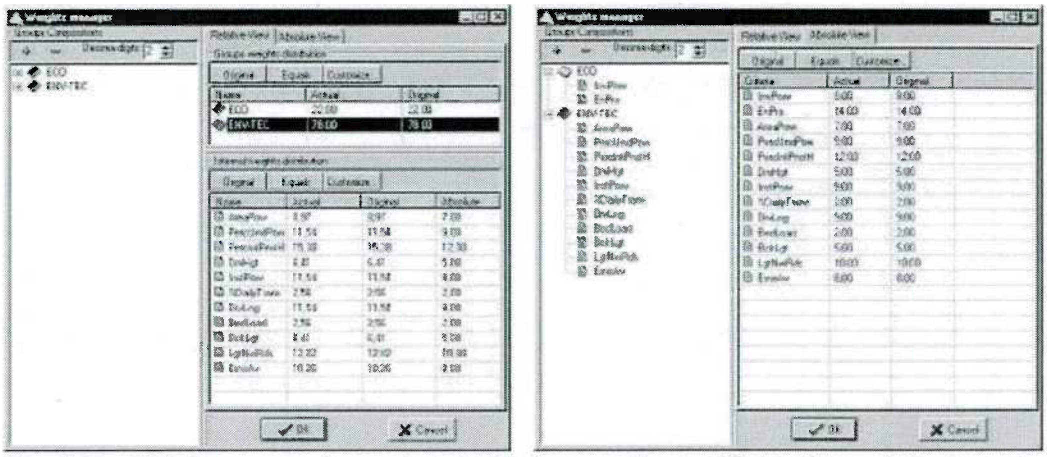


Fig. 8.25 – Weights manager form assessed with the properties specified in the previous chapter to perform an example of sensitivity analysis with 2 homogeneous groups of criteria

The command **Evaluation/Choose Indexes...** recalls the same procedure for selecting indexes in single run analysis (see pag. 84). The command **Evaluation/Set Weights...** recall the procedures described in the previous paragraph for managing the weighing system: in this case, what is essential for sensitivity analysis is the method for clustering criteria into groups (say, the composition of criteria in each folder set) and in particular the number of groups (= *folder sets*) we want to assess to perform such an analysis.

Different types of analyses will be carried according to the selection of 2 or 3 groups of criteria.

SENSITIVITY ANALYSIS WITH 2 HOMOGENEOUS GROUPS OF CRITERIA

Analytical details on such an argument are given at § 7.6.

For viewing the method and its results let's go to consider the demo example already discussed in the previous chapter. So, the criteria included in our original impact matrix must be here clustered into 2 groups, that is:

- **ECO**: Economical-related criteria (including only the criteria *EnPro* and *InvPow*);
- **ENV-TEC**: Environmental- and Technical-related criteria (including all the other remaining 11 criteria).

Let's then go to manage the weighing system in order to assess the weight situation presented in **Fig. 8.25**.

☞ **Important**: *What is essential here is to set up, besides the logic way of including one criterion into this or that group, the* ***relative weights*** *given to the criteria within each group. These can deeply influence the final results.*

Let's suppose again to select all the proposed indexes for the analysis. Note that here only the indexes derived from weighted functions can be selected, being the other (from simple, unweighted functions) not influenced by the variation induced by the sensitivity analysis on the weighing system.

Once the above index and weight selections have been performed, run the **Evaluation/Compute...** command. After few second, the list of the selected indexes appears on the memo box in the upper part of the main form (Fig. 8.24). This means that computations have been all completed.

At this point we have to select one specific index (for example, "*synthetic*") for obtaining on the video the situation with the **3 forms** presented in **Fig. 8.26**:

a) the *main form* already described, for selecting the index to be used for carrying out the analysis at hand; to select the index, click with the mouse button on its label name on the upper box of the form;
b) a *graphic form* representing the main results of the sensitivity analysis;

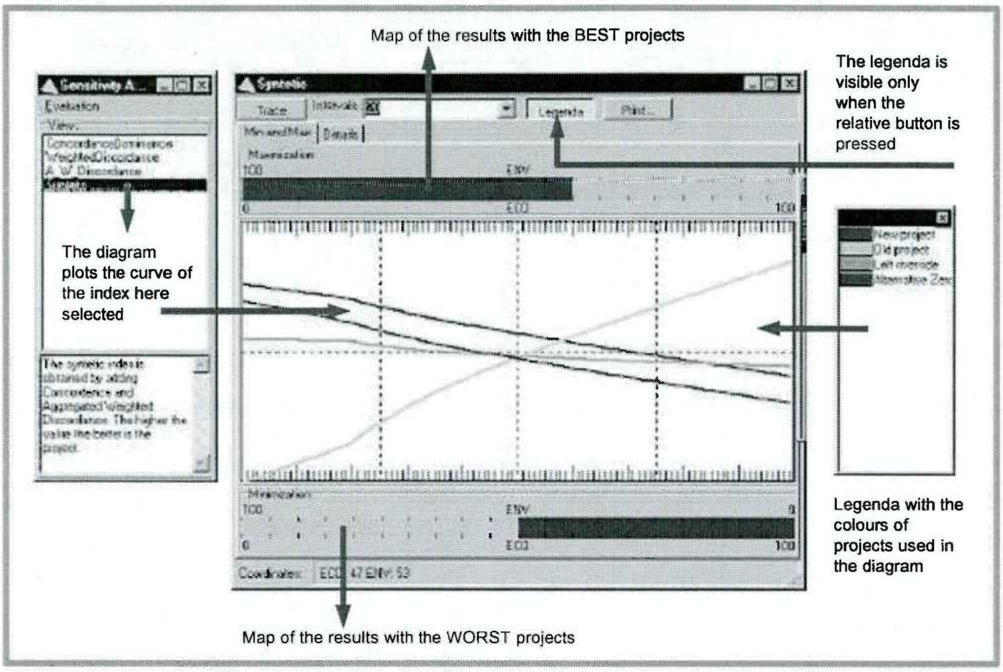


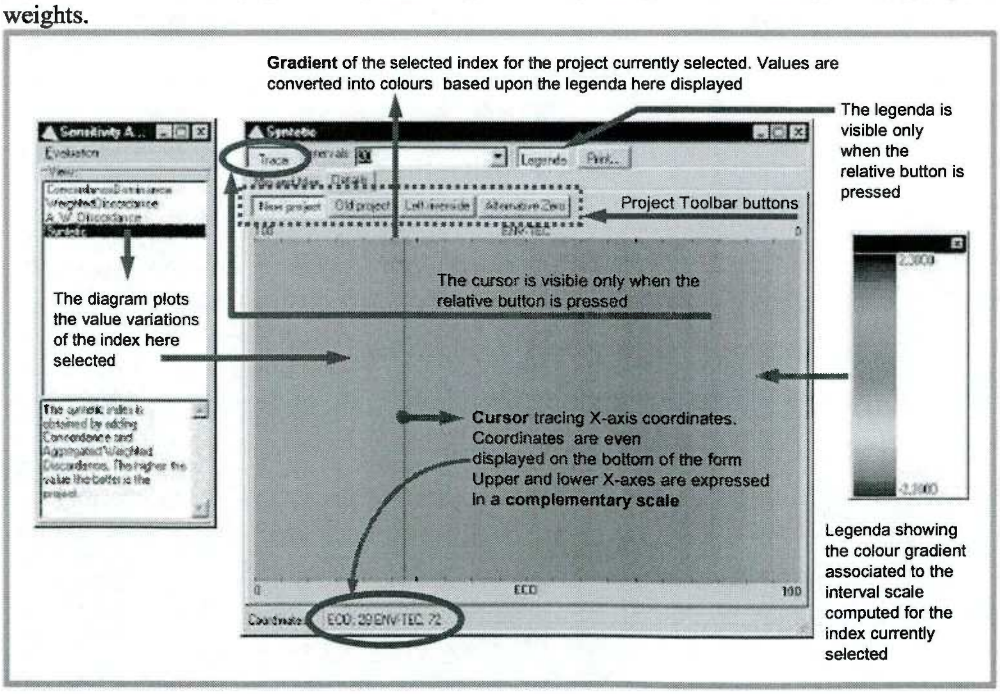
Fig. 8.26 – Results of a sensitivity analysis on 2 homogeneous groups of weights: pattern of the selected analysis indexes and maps of best and worst results.

c) a small *legend* form, visible only if its relative button on the top of the previous form is pressed; the legend here provides the colours by which each project is plotted in the main diagrams of the 2nd form.

The *graphic form* has 2 pages:

- **Min and Max**: providing the graphic results on the *worst* and the *best* projects, once all the alternatives have been ranked according to the index currently selected (this is the active page shown by Fig. 8.26, viz. the one that is active when the form is created by *HYPSE*);
- **Details**: presenting more detailed informa-

Fig. 8.27 – "*Details*" page when performing sensitivity analysis on 2 homogeneous groups of weights.



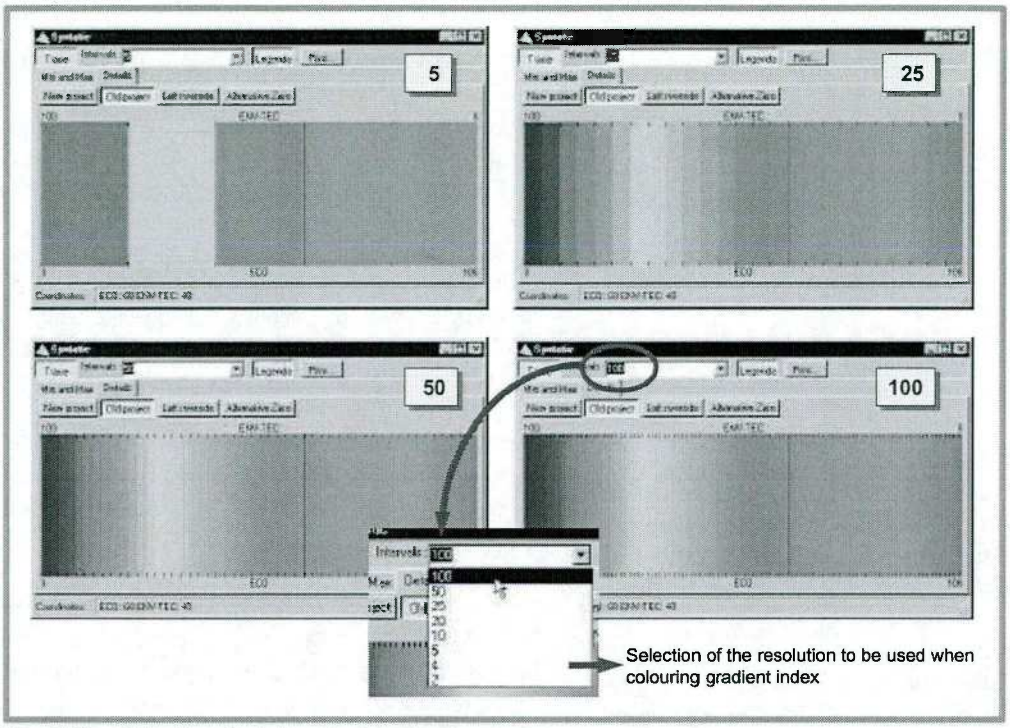


Fig. 8.28 – Selecting the interval of the **gradient index**

tion – again in a graphic form - on the pattern of the index currently selected, for each project included into the analysis (**Fig. 8.27**).

The former page provides an immediate understanding of all the possible final ranked situations obtained when the weighing system is made to vary according to a complementary scale (0÷100) between the 2 selected groups of weights. The results are mapped into two rectangular diagrams:

a) the top one, showing the results with the **best** projects (say, the projects that for each weight combination have achieved the most favourable analysis index);
b) the bottom one, showing the results with the **worst** projects (say, the projects that for each weight combination have achieved the least favourable analysis index).

The projects are represented throughout colours: colours associated to each project are shown by above said legend.

A *central main diagram* is displayed between the top and bottom ranked results. It plots as many curves as the projects in the problem at hand are. Each curve represents the pattern of the value of the analysis index currently selected for each project (the synthetic one in the example of Fig. 8.26). The shape of the curve provides information on the variational sensitivity of the index associated to each projects.

Thus in the example here considered one can note that *"Old project"* is very sensitive to weight variations, passing very easily from a *worst* condition (when the ECO group has a relative importance lower than 50%) to a *best* condition (when the ECO group has a relative importance greater than 58%). On the contrary, the *"Left riverside"* project is never ranked as best or worst project; it has a positive trend (increasing the value of the synthetic index) when the ECO importance decreases; but these variations occur according to a curve with low slope. This is configured as a typical compromise solution.

In practice, the curves plotted in Fig. 8.26 are the *HYPSE* version of the diagram shown by Fig. 7.6.

The *Details* page of the graphic form shows - for each project – the **gradient** of the analysis index currently selected (Fig. 8.27). Such a gradient is again presented in a graphic form, linking the index values to a scale of colours as indicated in the legend form (that changes its information content when the *Details* page becomes active).

*The metaphor here adopted associated the best index results to the **dark blue** and the worst index results to the **red** colour.*

In practice, such a diagram proposes a graphic version of the diagram described in Fig. 7.5: each point on the X-axis is a standpoint configured by a particular set of weight values. Only the index of one project at time can be viewed. To select another project, press the button with the project's name on the Toolbar located below the main diagram.

The *resolution* by which the coloured gradient index is displayed in the diagram of Fig. 8.27 can be set by the user selecting the interval scale of analysis from the combo box located on the top of the form (see **Fig. 8.28**). This selection consists in fixing an integer number that is a correct sub-multiple of 100 (2, 4, 5, ..., 100). Higher the number, better the graphic resolution but even higher the computation time to display the draws on the video. By default, *HYPSE* proposes a resolution scale of **20**. If there are no PC-system constraints, select 100 for getting the best plotting definition.

Whatever the case, when running the *Sensitivity Analysis* procedure, *HYPSE* computes all the weight combinations with a scale step equal to 1 (thus we have 100 iterative runs when a sensitivity analysis with 2 homogeneous groups of criteria is performed). So, drawing the diagrams with an interval scale lower than 100 means to compute an "average" index among all the indexes included in that particular interval scale (viz. if we select an interval scale of 5 – as indicated in the upper left diagram of Fig. 8.28 – *HYPSE* will produce a diagram with 5 distinct bounds; each bound includes 100/5 = 20 independent runs; the average index among these 20 runs will be computed, then linked to a colour according the colour palette presented in the legend form and finally plotted).

SENSITIVITY ANALYSIS WITH 3 HOMOGENEOUS GROUPS OF CRITERIA

Analytical details on such an argument are given again at § 7.6.

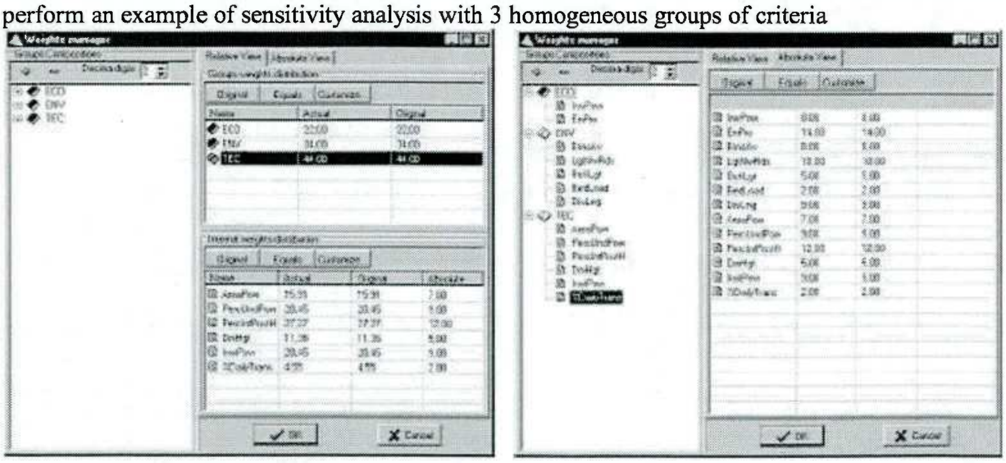
For viewing the method and its results let's go to consider the demo example already discussed in the previous chapter. So, the criteria included in our original impact matrix must be here clustered into 3 groups, as indicated in Table 7.4, where the **ECO**, **ENV** and **TEC** typical *HYPSE*'s groups were there proposed.

To carry out such a demo exercise, let's go to manage the weighing system in order to arrange the weight situation presented in **Fig. 8.29.**

Such a profile corresponds to the standpoint named **Designer's view** in the priority matrix presented by Table 7.6.

The sensitivity analysis must be carried following the preparation steps already described for the analysis with 2 homogeneous groups. Thus, once the index and weight selections have been performed, run the **Evaluation /Compute...**command. In this case the computation time is strongly longer if compared with the one required for the 2-group analysis. In fact we have an exponential increase of the computation cases (100^2): for the example at hand, when *HYPSE* is run on a PC with a 133 MHz Pentium processor, the computation time is approx. equal to 200 s if all the indexes have been selected for the analysis. The user is warned that computations have been all completed when the list of the selected indexes appears on the memo box in the main form upper part of the sensitivity analysis procedure.

Fig. 8.29 – Weights manager form assessed with the properties specified in the previous chapter to perform an example of sensitivity analysis with 3 homogeneous groups of criteria



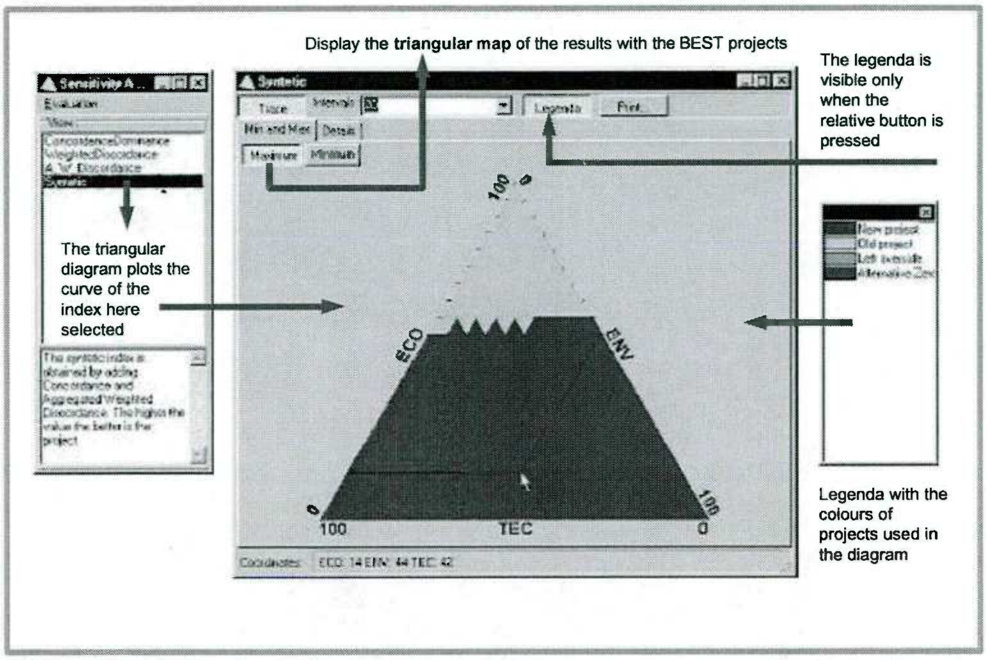
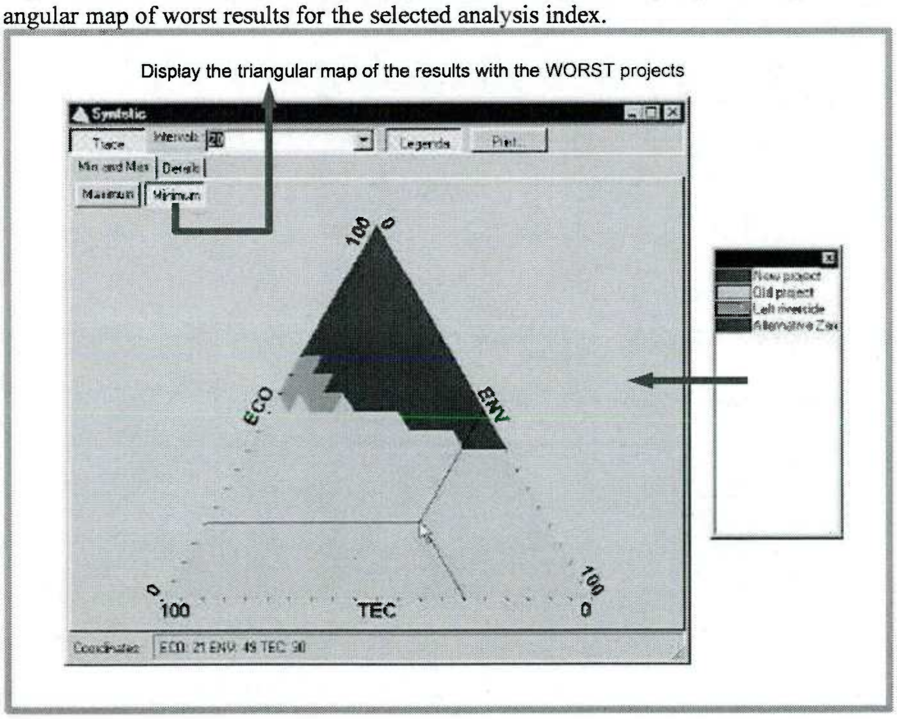


Fig. 8.30 – Results of a sensitivity analysis on 3 homogeneous groups of weights: triangular map of best results for the selected analysis index.

At this point we have to select one specific index (for example, "*synthetic*") for obtaining on the video the situation with the <u>**3 forms**</u> presented in **Fig. 8.30**, and analogous to the one already described for the 2-group sensitivity analysis.

The most evident difference regard the central graphic form. Here a triangular diagram representing the graphical map of the **best** results is plotted. Again, a colour is linked to each result,

Fig. 8.31 – Results of a sensitivity analysis on 3 homogeneous groups of weights: triangular map of worst results for the selected analysis index.



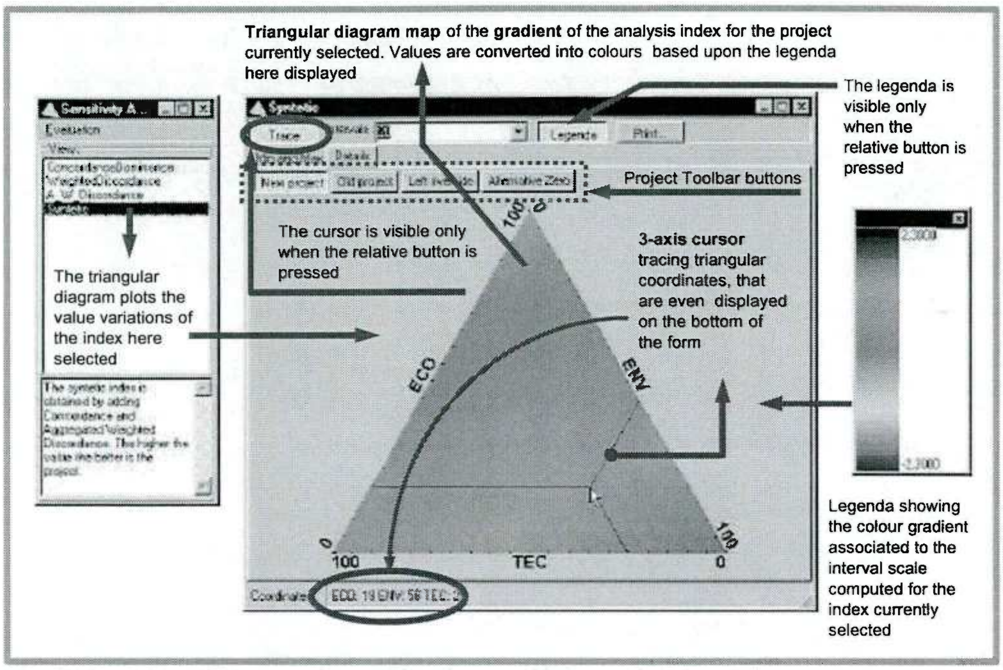


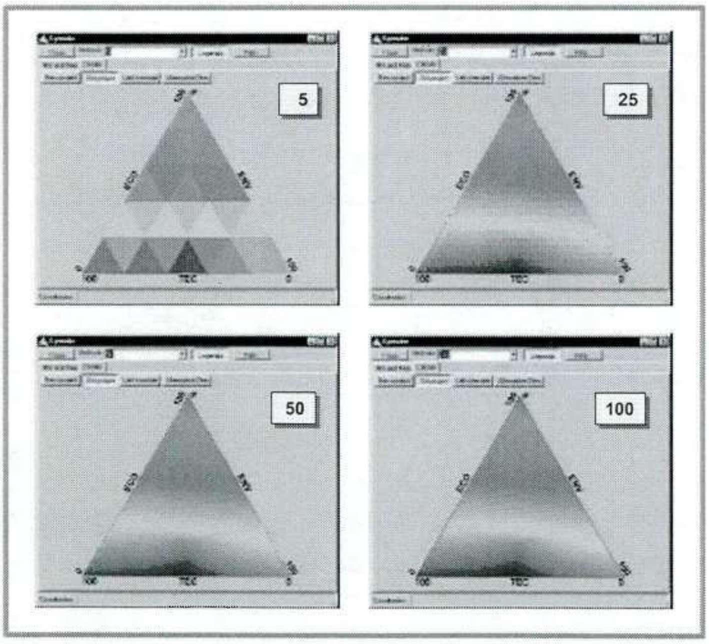
Fig. 8.32 – "*Details*" page when performing sensitivity analysis on 3 homogeneous groups of weights.

so that the situations associated to the different standpoint can be easily evaluated as a whole.

Below the triangular diagram there are 2 buttons:

- **Maximum**, for viewing the map with the **best** projects (say, the projects that for each weight combination have achieved the most favourable analysis index); this is the case that is automatically displayed by *HYPSE* when starting the presentation of the graphical results of the sensitivity analysis;
- **Minimum**, for viewing the map with the

Fig. 8.33 – Examples of resolution levels when the map of the analysis index gradient is displayed



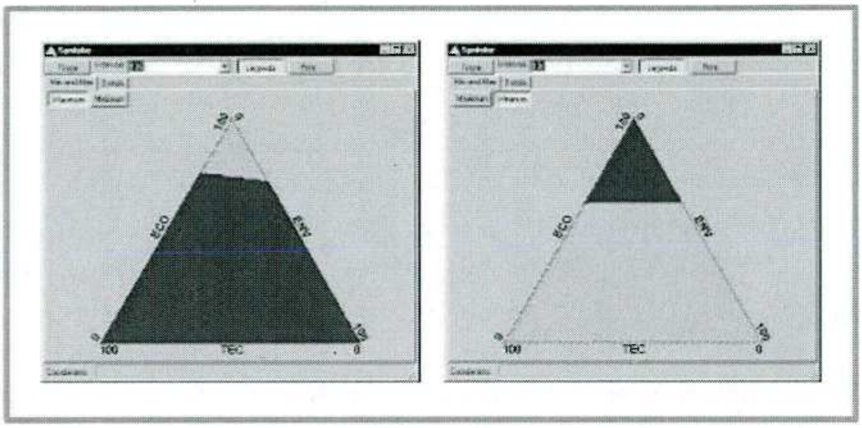


Fig. 8.34 – Triangular maps of the best and the worst projects, calculated setting to *equal* the relative weights of criteria inside an homogeneous group

worst projects (say, the projects that for each weight combination have achieved the least favourable analysis index, **Fig. 8.31**).

It can be noted that the **New project** solution is ranked as the best solution for a great part of the triangular area. It leaves this "favourable" position only when economical-related and technical-related factors tend to prevail. In these cases the most preferred solutions become **Old project** and **Alternative zero**, respectively. Here again, **Old project** is found to be very sensitive to weight variations. In fact, it even results to be the worst solution in the major part of the triangular area. And this is partially true even for the **Alternative zero.**

To obtain a more exhaustive and comprehensive explanation of the global analysis, the *Details* page can be even here selected. In a way similar to the 2-group analysis, the map of the value of the selected indexes are then displayed on further triangular diagrams (**Fig. 8.32**).

For each index, the stability (or sensitivity) of the final results can be even evaluated viewing the graphical gradient for any selected index.

The graphical resolution analysis can be again set by the user. The default value is 20, but a better definition (50 or 100) should be expected for more precise evaluations. In this 3-group analysis case, higher the resolution, higher the time required by the PC for plotting the triangular gradient map. Here, it must be considered that the unit step of the analysis is represented on the diagram by an unitary equilateral triangle having a 1x1x1 size. When a resolution of 100 is selected, each case analysed by *HYPSE* points to a sets of triangles of such a size. But when a lower resolution is desired, bigger triangles are plotted, each referring to the average of all the unitary triangles that are included in it.

Some examples of different resolution levels are given in **Fig. 8.33.**

It must be further stressed that the analytical and graphical results of any sensitivity analysis depends mostly on the *relative weights* of criteria, that is the relative priority assumed by each criterion inside its homogeneous group. The results shown by Figs. 8.30 and 8.31 refer to the relative weight situation proposed by Fig. 8.29, that is the standpoint "*Designer's view*" in Table 7.6. Note that all the other standpoints in the same Table have different relative weight profiles. More precisely, the standpoints from I to VII have the common features of an equal distribution of the criterion priorities inside each homogeneous group.

If we perform a further sensitivity analysis setting this new basic feature (that is pressing the button "*Equal*" inside the "*Internal weights distribution*" box of all the 3 groups here considered), we will obtain the results shown by **Fig. 8.34.**

Note the different distribution inside the triangular diagrams. The graphic output related to the best solutions of Fig. 8.34 is analogous to the one obtained in the previous chapter and presented by Fig. 7.9.

All considered, when performing a sensitivity analysis these aspects must be carefully taken into consideration. The stability of the final results must be even evaluated with respect to the priorities inside each group.

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