CALCULATION OF ENVIRONMENTAL IMPACT TOOL

ECCO2

SUMMARY

INTRODUCTION

ECCO2 is a calculation tool designed to estimate the effects of utilizing different job mix formulas, type of aggregates, bitumens, additives, recycling rates, production temperatures, fuels, yields and transportation distances, among others, on the **environmental impacts of bituminous mixes**. It is based on theoretical environmental accounting, although it incorporates various empirical approaches, whose precision is expected to improve as results of successive measurements made on site are accumulated.

ECCO2 has been based on the **Life Cycle Assessment methodology** to prevent mere displacements of environmental loads between different life cycle stages or productive processes from being valued as environmental improvements. In this Manual, the calculation models used, the sources of data, the alternatives that may be subject to comparison and their definition through user forms are described.

ANALYSIS APROACH

2.1 Purpose and Scope

In ECCO2, a Life Cycle Assessment (LCA) of the type called "cradle to gate" has been proposed, since **they add to the impacts resulting from the extraction, transformation and transportation of raw or secondary materials, energy products and products from the manufacture, transportation and laydown of bituminous mixes**. Therefore, it facilitates the direct comparison of alternatives from which similar behaviours are expected in service during the same useful life. Under the previous assumption, this is an approach that does not detract from the conclusions that emerge from the results obtained. Naturally, by introducing the appropriate corrections, ECCO2 can also be useful for comparing solutions with different design periods.

In ECCO2, processes external to the product system have been considered, regardless of their contribution to the LCA, those relative to the manufacturing of facilities, the asphalt mix facility and the machinery and vehicles used in their production, transportation and laydown. Also not accounted for are the eventual contributions of processes related to maintenance, repair or replacement of wear material of such equipment.

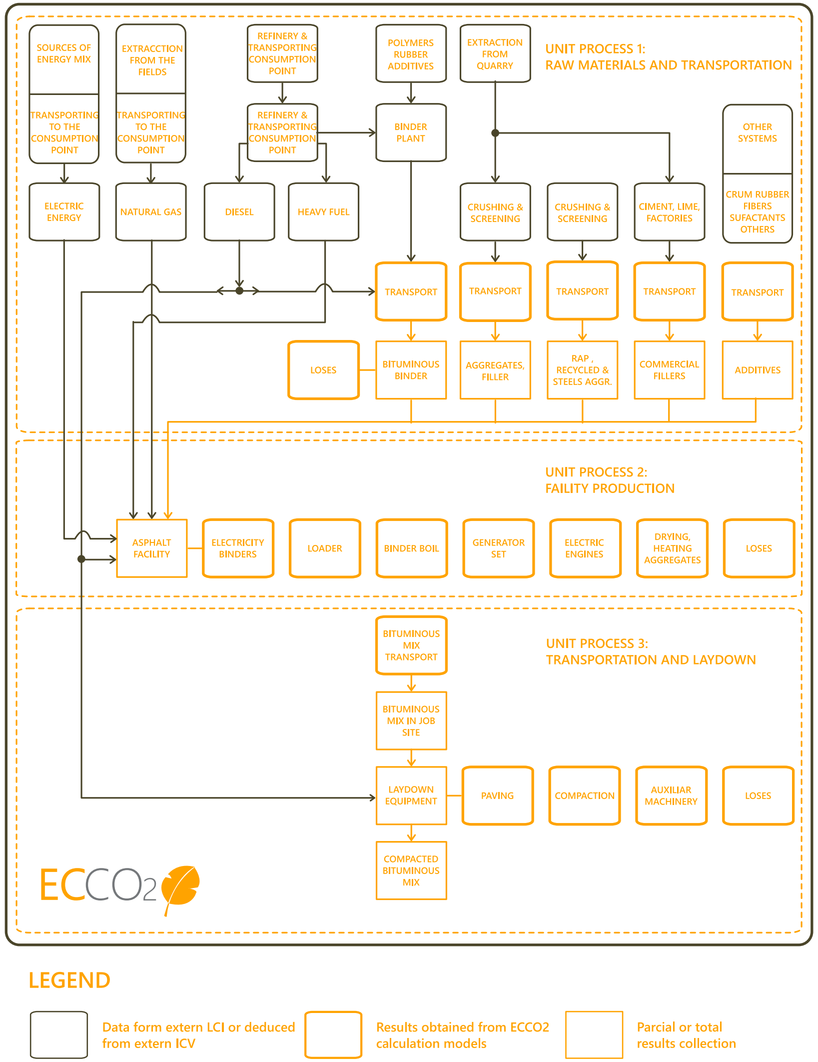
The results of the Life Cycle Assessment are obtained, for the functional unit, one ton of placed bituminous mix although, as it is obvious, they may also refer to any other amount or to a certain pavement surface if the density and thickness data of the finished layer are available.

ANALYSIS APROACH

INVENTORY ANALYSIS

Whenever it has been possible, we have resorted to recognized, public access, and selected databases as the most representative of the modes of production that are to be analysed. Our own elaborations have also been made (data obtained through adjustments, deductions or sum of data from external Life Cycle Inventory Analysis [LCI]).

The inputs and outputs of each sub process and unit process considered have been obtained through our own calculation model. Figure 1 is a flow diagram that helps identify sub processes resolved by assigning inventory data and sub processes that have required the development of their own calculation model. The latter respond to the following approaches:



ANALYSIS APROACH

Unit Process 1 Raw Materials and their Transportation

The consumption of each fraction of natural or artificial aggregate is obtained from the respective proportions by weight established in the cold feed, and from the expected losses during transportation and storage operations, where appropriate, and from those expected during laydown.

The consumptions of bitumen, emulsion, RAP and other additions are calculated from the respective proportions by weight provided in the working formula.

The diesel consumption associated to the transportation of each raw or secondary material is a function of the transportation distance and the net load and unit fuel consumption assigned to a transportation vehicle, which in turn depends on the type of engine size considered (conventional, Euro I, II, III, IV or V).

Unit Process 2: Facility Production

The aggregate's losses the production facility are obtained by differences between the cold feed and the hot feed.

The electric energy demand of the network or diesel in a generator set and boilers, as the case may be, is deducted from the installed power and the estimated hours of operation of each piece of equipment. ECCO2 assigns, by default, the corresponding powers depending on the capacity of the production facility and the type of source considered.

The diesel consumption of the loader is derived from its power, hours of usage and type of engine (Stage I, II, IIIA, IIIB, IV and V).

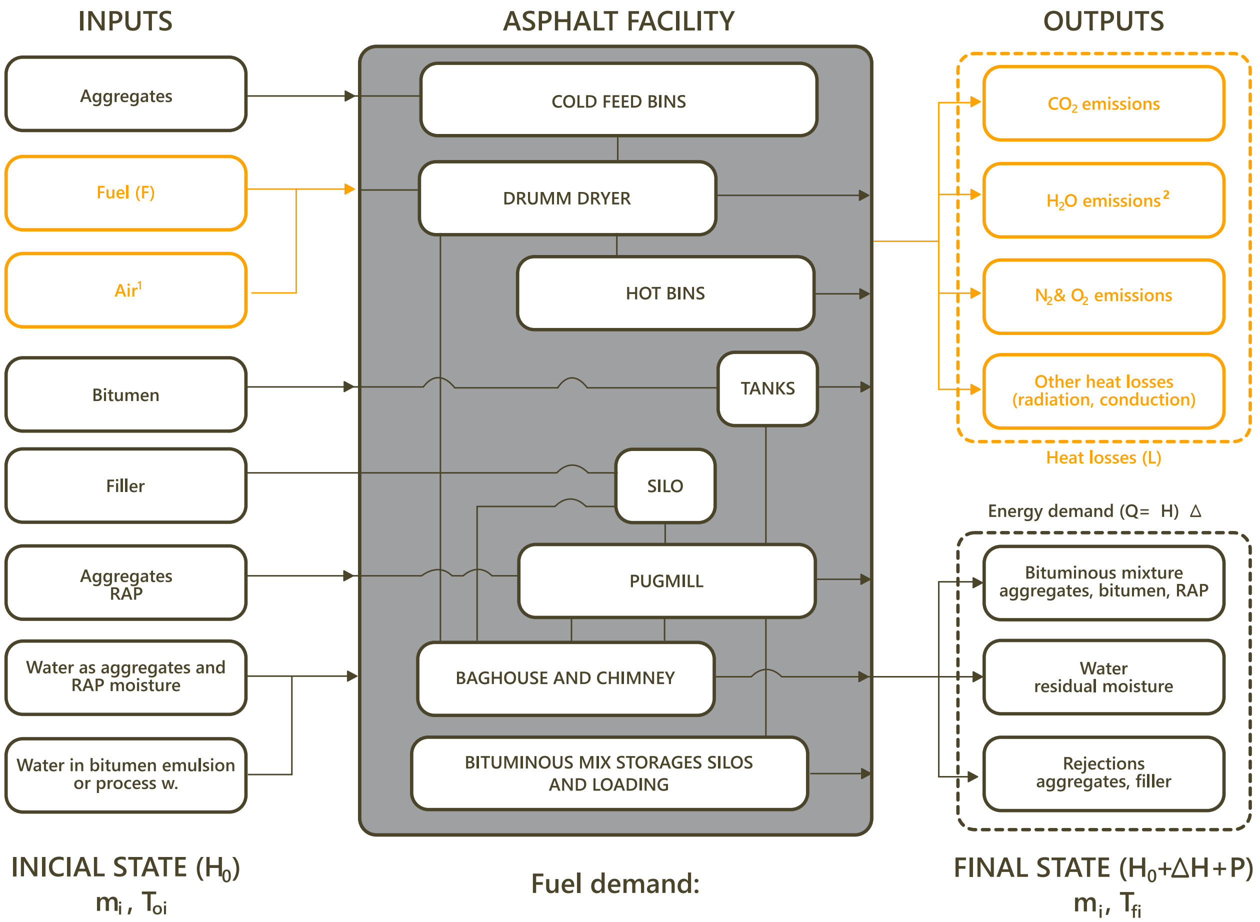
The energy demand that must be satisfied for the drying and heating of aggregates is obtained by change of enthalpy of the components of the bituminous mix and the heat losses calculated in the chimney by radiation and conduction due to the heat invested in the heating of the facility itself.

ANALYSIS APROACH

The figure illustrates the approach of the thermal balances developed to obtain the fuel demand. Although inside the Production Facility box, attempts have been made to represent the flow corresponding to a certain type of facility, it takes into account that, since enthalpy is a state function, its variation depends only on the initial and final conditions of the system under analysis. The configuration of the facility, therefore, does not affect the validity of the model as long as the heat losses and residual moisture present in the bituminous mix at the discharge of the facility are estimated with sufficient approximation.

ECCO2 has an empirical approach to heat losses from radiation, conduction and heating of the facility itself, and a model to estimate the residual humidity of the bituminous mix according to the manufacturing temperature, which completes the information required to calculate the theoretical demand made out of fuel.

ANALYSIS APROACH



(1) Stoichiometric ari necessary for combustion + excess air + leackage air.
(2) Water combustion product + aggregate moisture + RAP moisture + emulsion water or process water - residual moisture.
(3) LCV_F : Low calorific value of fuel.

ANALYSIS APROACH

Unit Process 3: Transportation and Laydown of Bituminous Mix

As in the transportation of raw materials, the diesel consumption associated to the transportation of bituminous mix from the facility to the worksite is obtained from the distance of transportation, net load and unit fuel consumption assigned to a transportation vehicle, which in turn depends on the type of engine size (conventional, Euro I, II, III, IV or V).

The diesel consumption of the laydown equipment, like the loader in the production facility, is derived from its hours of usage, power and type of engine (Stage I, II, IIIA, IIIB, IV or V).

ECCO2 databases also include the specific heats of rounded and crushed aggregates, bitumen, liquid and vapour water, oxygen, nitrogen, carbon dioxide and steel, the lower heat value (LHV) of diesel, heavy fuel, and natural gas, the stoichiometric ratios of combustion reactions and excess air proportions over stoichiometry typically used in production facilities, taken from various sources or from our own measurements and estimates.

IMPACT ASSESSMENT AND INTERPRETATION OF RESULTS

ECCO2 has been configured to calculate the following eight impact categories: Total Consumption of Raw Materials, Abiotic Depletion, Accumulated Energy Demand, Climatic Change Indicator, Acidification, Eutrophication, Formation of Photochemical Oxidants and Waste Recovery. The latter is obtained by subtracting the difference between waste used and waste generated from total raw material consumption and created to recognise its eventual reduction as an environmental improvement of interest. The characterization factors used in the different impact categories are taken from TEAM, ADF and IPPC.

The calculation results are presented in the form of a histogram together with the numerical values per unit process. Up to four distinct manufacturing alternatives can be compared simultaneously.

CALCULATION TOOL OPERATION

Through ECCO2, data collection, variable introduction, equation resolution and presentation of analysis results have been systematized.

In its current version, ECCO2 utilizes up to a total of 92 production variables. The user can assign values to 75 of these variables while the rest are dependent variables or are determined by default. Together, they help distinguish the environmental effects of the ambient temperature and humidity of aggregates, different type of aggregates and bituminous binders, waste recovery and additives usage, job mix formula, facility’s energy source, bituminous mix temperature, daily output of the production and laydown, composition and characteristics of machinery equipment and transportation distances, among others.

In the version of ECCO2 currently available on the www.arno.es website only, the impact category “Climatic Change Indicator” (CCI), or carbon footprint, is enabled. The rest of the categories are planned to be included in successive versions, where the predictions provided by the heat loss or residual moisture estimation models can also be replaced by data obtained from actual measurements.

Data entry is done using the three forms reproduced in Figures 3, 4 and 5, which combine drop-down lists with cells where numerical values must be entered. When opening for the first time, each form shows in all its fields selections and values set by default in order to simplify the introduction of data. Once the calculations have started, the user can move between forms, keeping the most recent data and saving data and results if indicated in the final form

RAW MATERIALS AND THEIR TRANSPORTATION

Raw materials and transportation

Raw materials | Production | Laydown | Calculation | Restart

Cold feed

	Nature	Content %		Distance	
Fine aggregate 1	Aggregate crushed	40	s/a	5	km
Fine aggregate 2	Aggregate not crushec	10	s/a	15	km
Coarse aggregate 1	Aggregate crushed	20	s/a	60	km
Coarse aggregate 2	Aggregate crushed	20	s/a	60	km
Losses in stockpiling and transportation		3	s/a		

Hot combination

	Nature	Content %		Distance	
Commercial filler	PM Limestone	2	s/a	110	km
Additive 1	NO	0	s/m	110	km
Additive 2	NO	0	s/bitumen	90	km
RAP	RAP Classified	10	s/m	15	km
RAP bitumen content		4	s/m		
Bitumen content in bituminous binder		100	s/m		
Total bitumen content of asphalt mixture		5	s/m		
Added bitumen in the asphalt mixture	PMB 45/80-65	4.6	s/m	160	km

Raw material transportation

	Engine standard	Net load		Comsuption (100Km)	
Type of truck	Euro I	25	t	30.1	l

RAW MATERIALS AND THEIR TRANSPORTATION

This form helps consider, within the cold feed, the combination of up to four fractions of aggregate, in any proportion (two of fine aggregate and another two of coarse aggregate), of different natures in the table called "cold feed". The proportion of commercial filler, like that of additive 1, RAP and total bitumen must be established as a proportion over mixture in the corresponding box called "hot feed" that completes the previous dosage. In addition, the incorporation of a second additive, measured in proportion to the added bitumen, is planned. The working formula is fully described when the user indicates the bitumen present in the RAP, where appropriate, the residual binder content in the bituminous emulsion and the nature of all the components of the mixture.

If the selected proportions are insufficient to obtain 1,000 kg of material per ton of bituminous mix, ECCO2 shows a warning that requires correcting the dosage entered. A warning also appears if the dosed materials add up to more than 1,060 kg per ton of mixture, although in this case the user can cancel the warning and continue without making any correction. And a warning also appears when an additive is selected for which Life Cycle Inventory Analysis is not available in ECCO2.

The values that cannot be modified by the user are shaded. This is the case of residual bitumen when the selected binder of bitumen, out of the proportion of added bitumen, which ECCO2 calculates by the difference between the total bitumen and that contributed by the RAP, out of the net load and the unit consumption of the transportation vehicles. For the purposes of fuel consumption and CO2 emissions, only a distinction is made between "conventional" and other European motorization standards. Consumption estimates refer, in all cases, to vehicles with 25 t of net load that make the journey with a full load and return without a load.

FACILITY PRODUCTION

FACILITY PRODUCTION

In this case, it is about defining the aspects related to the configuration of production facility and its operation, which exert the greatest influences on CO2 emissions in this subsystem defined as unit process 2.

The choice between different configurations and operating regimes is made indicating the capacity of the facility, its daily average production, hours of actual operation, number of production interruptions, and the operating time of the binder heating system (equivalent time of usage at its nominal power). ECCO2 assigns values to the power of electric engines and the heating system according to the capacity of the facility, according to those established in its database that are considered representative of the usual discontinued facilities in Spain.

In this form, the different energy sources used and a loader model (Caterpillar or equivalent) and the European (Stage) or American (Tier) standard of your engine must be selected.

In relation to the different fractions of aggregates and RAP, the user must indicate their humidity and temperature in the stockpiles of the facility. The user must also enter ambient temperature values of the bituminous binder, the manufacture of the bituminous mix and, if applicable, of the process water. The gas outlet temperature has been set at 115 ºC. If it is a hot or semi-hot mix asphalt (produced at more than 100 ºC), the introduction of more information is not required.

In the case of temperate mixtures with bitumen, the technology used is considered to be based on the induced foaming of the binder by means of water coming from the moisture of one of the fine aggregate or RAP fractions, by means of process water or by adding both options. The calculation model developed to calculate process water gets its proportion as a difference between the water contributed by that route and the water considered necessary to cause the timely foaming of bitumen by this procedure (1.5% s/a). The user must indicate, therefore, which of the indicated fractions is introduced directly into the mixer, if applicable.

TRANSPORTATION AND LAYDOWN

Transportation and laydown

Raw materials | Production | Laydown | Calculation | Restart

Conditions,operating times

Distance between facility and laydown site	60	km	Layer thickness	50	mm
Daily ouput	800	t/d	Compacted layer density	2.4	t/m^3
Losses in laydown operations	2.5	s/m	Functional unit	1	t

Laydown equipment

	Type	Power	Daily use
Transfer vehicle	ROAD SB2500	233 kW	
Paving machine 1, Vögele or similar	SUPER 1900	150 kW	
Paving machine 2, Vögele or similar	NO	- kW	
Double drumm roller 1, Dynapac or similar	CC 4200	97 kW	
Double drumm roller 2, Dynapac or similar	NO	- kW	8 h
Double drumm roller 3, Dynapac or similar	NO	- kW	
Pneumatic tired roller, 1	24 - 30 t	90 kW	
Pneumatic tired roller, 2	NO	- kW	
Pneumatic tired roller, 3	21 - 24 t	74 kW	
Milling machine, Wirtgen or similar	W100 Ri	160 kW	2 h
Compact loader with broom, Bobcat or similar	S 510	36.4 kW	4 h

Type of trucks and machinery

Trucks	Euro II	Machinery	Stage II (Tier 2)

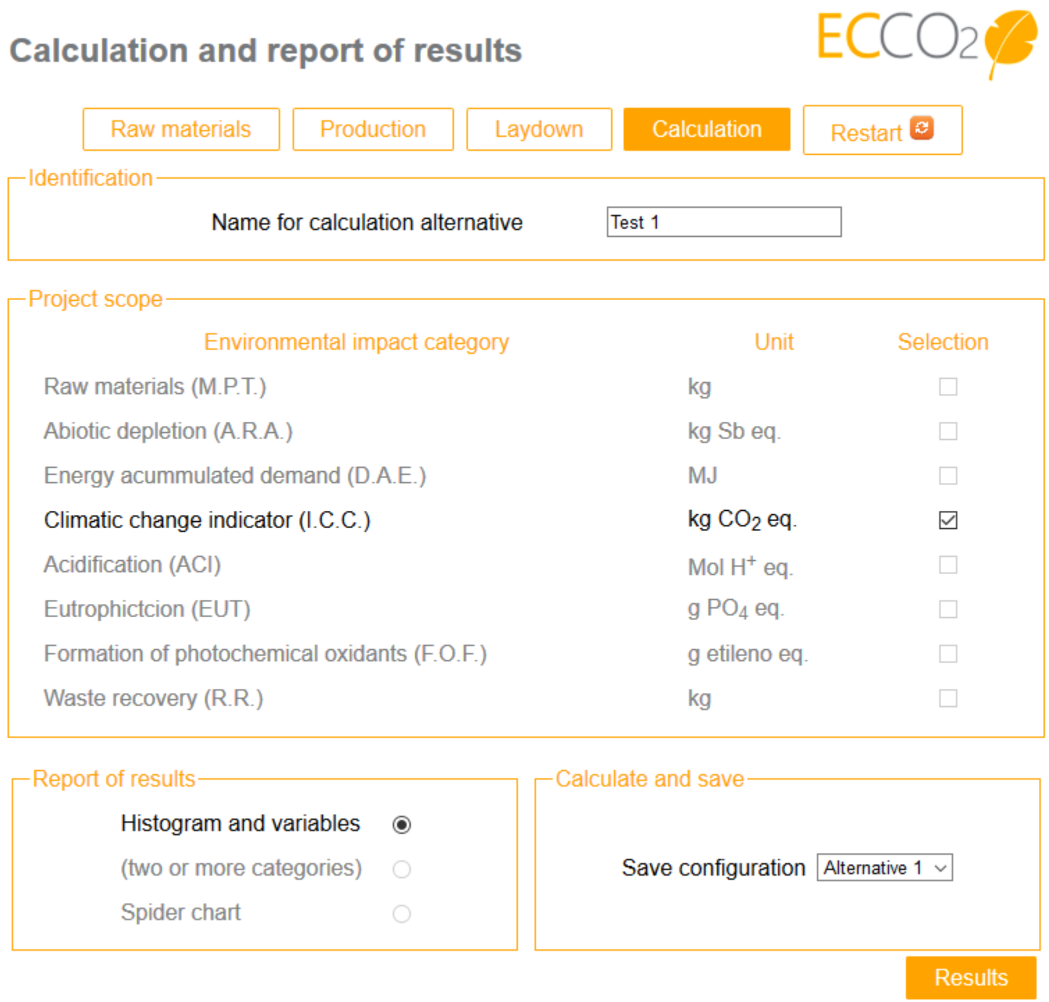
TRANSPORTATION AND LAYDOWN

Finally, through this third form, the necessary data entry is complete to make the calculations. The user must indicate the transportation distance from production facility to the worksite, the composition of the spreading and compaction equipment, the performance of the laydown, the European standard most representative of the engines in the expected transportation vehicles, the European or American standard of the laydown machinery engines and use hours.

The laydown equipment can consist of one or two pavers, two or three double drum rollers, and one or two tire compactors. Except for the latter, which are selected according to their operating weight, the rest of the machines are described as similar to some of the most frequently used models in Spain.

In addition, a compact loader with broom and a milling machine can be included as auxiliary machinery, each with its own average daily operating time and different from that indicated for the laydown equipment.

CÁLCULATIONS

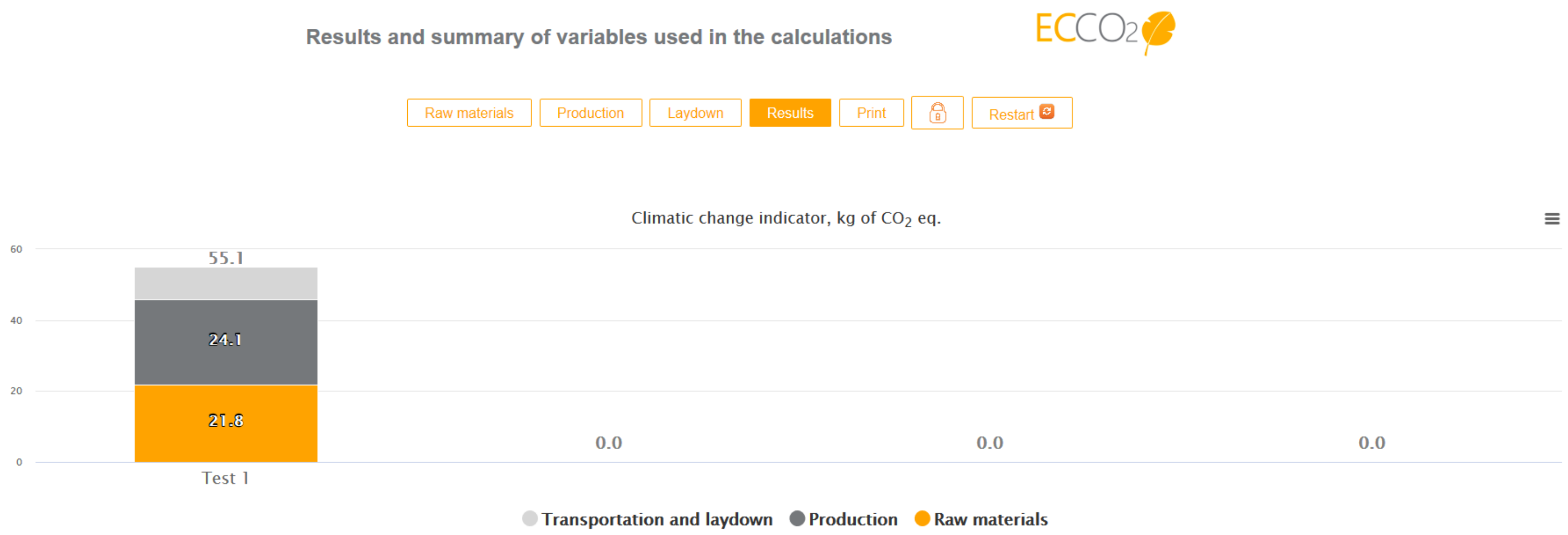


Before obtaining the results, it is recommended to identify the alternative in calculation in the "Identification" box and indicate the position in which it will appear in the histogram in the "Calculate and save" box.

RESULTS

The figure shows a presentation of the calculation results. Up to four production alternatives can be compared simultaneously, sorted according to what is indicated in the calculation form.

From this screen, you can return to any of the previous screens to make a new calculation by addressing only the form that needs to be modified. ECCO2 keeps all the values that are not modified and will present as a new calculation alternative the calculation obtained with any partial modification.



RESULTS

Raw materials and transportation

		Test 1
1	Fine aggregate 1, proportion (%)	40
2	Fine aggregate 2, proportion (%)	10
3	Coarse aggregate 1, proportion (%)	20
4	Coarse aggregate 2, proportion (%)	20
5	Losses in stockpiling and transportation, (%)	3
6	Fine aggregate 1, nature	crushed
7	Fine aggregate 2, nature	not crushed
8	Coarse aggregate 1, nature	crushed
9	Coarse aggregate 2, nature	crushed
10	Fine aggregate 1, distance (km)	5
11	Fine aggregate 2, distance (km)	15
12	Coarse aggregate 1, distance, (km)	60
13	Coarse aggregate 2, distance (km)	60
14	Commercial filler, proportion (%)	2
15	Additive 1, proportion (%)	0
16	Additive 2, proportion (%)	0
17	RAP, proportion (%)	10
18	RAP bitumen content (%)	4
19	Bitumen content in bituminous binder (%)	100
20	Total bitumen content of asphalt mixture (%)	4.6
21	Added bitumen in the asphalt mixture (%)	5
22	Commercial filler, nature	Limestone
23	Additive 1, nature	NO
24	Additive 2, nature	NO
25	RAP, nature	RAP Classified
26	New bitumen, nature	PMB 45/80-65
27	Commercial filler, distance (km)	110
28	Additive 1, distance (km)	110
29	Additive 2, distance (km)	90
30	RAP, distance (km)	15
31	New bitumen, distance (km)	160
32	Trucks, carga neta (t)	24
33	Trucks, estandar motor	Euro I
34	Trucks, comsuption (l/100 km)	30.1

Facility production

		Test 1
1	Elevation snm (m)	<500
2	Capacity (t/h)	220
3	Daily production (t)	800
4	Operating hours in day (h)	6
5	Heating equipment operation (h)	4
6	Dryer-drum burner	Fuel oil
7	Facility engines, source	Generator set
8	Heating bitumen storage, sistema	Fuel oil boiler
9	Generator set, combustible	Diesel
10	Pala carregadora, model	CAT 950 M
11	Credit	Stage II (Tier 2)
12	Generator set, engine	Conventional
13	Fine aggregate 1, moisture (%)	2.5
14	Fine aggregate 2, moisture (%)	2.5
15	Coarse aggregate 1, moisture (%))	1
16	Coarse aggregate 2, moisture (%)	1
17	RAP, moisture (%)	5
18	Process water (%)	0
19	Residual moisture content (%)	0
20	Component of cold feed in the pugmill	Any
21	Ambient temperature (ºC)	20
22	Aggregates temperature	15
23	RAP temperature	15
24	Bituminous binder temperature	150
25	Process water temperature	15
26	Exhaust gases temperature	115
27	Bituminous mixture temperature	165

Transportation and laydown

		Test 1
1	Distance between facility and laydown site	60
2	Daily ouput	800
3	Losses in ladown operations (%)	2.5
4	Layer thickness, mm	50
5	Compacted layer density (t/m3)	2.4
6	Functional unit	1
7	Transfer vehicle, type	ROAD SB2500
8	Paving machine 1, type	SUPER 1900
9	Paving machine 2, type	NO
10	Double drumm roller 1, type	CC 4200
11	Double drumm roller 2, type	NO
12	Double drumm roller 3, type	NO
13	Pneumatic tired roller 1, type	24 - 30 t
14	Pneumatic tired roller 2, type	NO
15	Milling machine, type	W100 Ri
16	Compact loader with broom, type	S 510
17	Laydown equipment (h)	8
18	Milling machine, time	2
19	Compact loader with broom, time (h)	4
20	rucks, engine	Euro II
21	Machinery, engine	Stage II (Tier 2)

APPENDIX

Table A1: Provenance of the data in the Life Cycle Inventory used

PRODUCT	SOURCES OF INVENTORY DATA
Rounded aggregates	ECOINVENT [1] y EPLCA [2]
Crushed aggregates	ECOINVENT [1] y EPLCA [2]
Recycled aggregates	CAVIT 2002 [1]
Steel slag aggregates	CAVIT 2002 [1]
RAP without any treatments	Only impacts from trasnportation
RAP screened	Own estimates using data from ECOINVENT and Stripple [3]
RAP crushed and screened	Own estimates using data from ECOINVENT
Bitumen[4]	EUROBITUME [4]
Polymers modified bitumens	PMB 45/80-65 from EUROBITUME. Own estimates for other polymer modified bitumens, using data from EUROBITUME
Rubber impoved bitumen	Own estimates using data from EUROBITUME
Rubber impoved bitumen	Own estimates using data from EUROBITUME
High viscosity rubber modified bitumen	Own estimates using data from EUROBITUME
Bituminous emulsions	EUROBITUME

PRODUCTO	FUENTES DE LOS DATOS DE INVENTARIO
Modified vitumen emulsions	Own estimates using data from EUROBITUME
Cement	EPLCA
Quicklime	EPLCA
Calcium hydroxide	Own estimates using data from EPLCA
Cellulose fibers	Shen and Patel [5]
Synthetic zeolites	Fawer [6]
Crumb rubber	Only impacts from transportation
Boil diesel	ENERTRANS [7], National inventoriesof MITECO, CORINAE, CONCAWE, IPPC, EPA [8] and own estimates
Vehicles diesel	ENERTRANS, EMEP-EEA [9]
Machinery diesel	ENERTRANS, NRMM [10]
Heavy fuel oil	ENERTRANS, National inventories of MITECO, CORINAE, EPA [8]and own estimates
Natural gas	ENERTRANS, National inventories of MITECO, CORINAE, EPA and own estimates
Electric energy	MINETUR [7] , EURELECTRIC [8], and own estimates

APPENDIX

Tabla A2: Calculation models for inputs and outputs of UP-1, UP-2 and UP-3

PU 1: RAW MATERIALS AND TRASPORTATION	
Rounded, crushed aggregates and filler (m_i, kg)	$m_i = 1000 p_i (1-b_t)(1+\mu)(1+\varepsilon)$
RAP, fibres, CaO, $Ca(OH)_2$, natural or synthetic zeolites, crumb rubber (m_i, kg)	$m_i = 1000 p_i (1+\varepsilon)$
Binding activants, surfactants, viscosity reducers (m_i, kg)	$m_i = 1000 p_i b_h (1+\varepsilon)$
Bituminous binder (m_9, kg)	$m_9 = 1000 \frac{p_9}{b_r}(1+\varepsilon)$
Diesel for raw materials tasmportation (g_1, l)	$g_1 = 8 \cdot 10^{-4} c_t \sum_{i=1}^{9} m_i d_i$
Wasted products generated from raw materials (r_1, kg)	$r_1 = \mu(1+\varepsilon) \sum_{i=1}^{4} m_i$

APPENDIX

Tabla A2: Calculation models for inputs and outputs of UP-1, UP-2 and UP-3

UP2: ASPHALT FACILITY PRODUCTION	
Fuel in dryer drum of asphalt plant (f, kg)	$f = \frac{1}{PCI_f}(\Delta H_1 + \Delta H_2 + \Delta H_3 + L)$
Change of enthalpy of the bituminous mixture components (DH_1, kJ)	$\Delta H_1 = \frac{1}{1+\mu}\sum_{i=1}^{4} m_i (T_{MB} - T_i) CE_i + \sum_{i=5}^{9} (T_{MB} - T_i) CE_i$
Change of enthalpy of water present in bituminous mixture components or added (DH_2, kJ)	$\Delta H_2 = (\frac{1}{1+\mu}\sum_{i=1}^{4} m_i w_i (T_e - T_i) + \sum_{i=5}^{9} m_i w_i (T_e - T_i) + 1000 \cdot w_{10} (T_e - T_{10}))\, CE_w$
Ennthalpy of vaporization of waer (DH_2, kJ)	$\Delta H_3 = (\frac{1}{1+\mu}\sum_{i=1}^{4} m_i w_i + \sum_{i=5}^{9} m_i w_i + 1000 (w_{10} - w_r))\, E_w$
Process water inhalf warm mixes made with bitumen (w_{10}, %)	$w_{10} = 1000 \cdot (1{,}5 (1 - b_n) - w_{11})$ $w_{11} = 1000 (1 - \mu) m_1 w_1$ ó $w_{11} = 1000 (1 - \mu) m_2 w_2$ ó $w_{11} = 1000\, m_8 w_8$ *
Residual water content in bituminous mixtures made with bitumen $T_{MB} \geq 140$ºC	$w_r = 0$
Residual water content in bituminous mixtures made with bitumen, $T_{MB} < 140$ºC, (w_{res}, %)	$w_r = 0{,}5 - \frac{T_{MB} - 90}{100}$
Residual water content in bituminous mixtures made with bitumenous emulsion (w_{res}, %)	$w_r = 1{,}0 - \frac{T_{MB} - 90}{100}$

* According the selected component for its direct introduction in the pugmill

APPENDIX

Tabla A2: Calculation models for inputs and outputs of UP-1, UP-2 and UP-3

UP 2: ASPHALT FACILITY PRODUCTION	
Heat losses (L, kJ)	$L = L_1 + L_2 + L_3 + L_4$
Heat losses from steam productes in aggregates and RAP water content and process water (L_1, kJ)	$L_1 = (\frac{1}{1+\mu} \sum_{i=1}^{4} m_i w_i + \sum_{i=5}^{9} m_i w_i + 1000 (w_{10} - w_r) \cdot (T_h - T_e) CE_v$
Heat losses in combustion gases (L_2, kJ)	$L_2 = (f + (1+\alpha) a_{es} \cdot (1+\varphi))(T_h - T_a) CE_a$
Radiation and conduction heat losses (L_6, kJ)	$L_3 = k_1 t (T_1^4 - T_a^4) + k_2 t (T_2^4 - T_a^4)$
Energy used in heating elements of asphalt facility (L_4, kJ)	$L_4 = \frac{n_2 + 1}{n_1} m_c (T_3 - T_a) CE_a$
Energy from electricity network (E_e, kJ)	$E_e = \frac{3600}{n_2} (P_1 h_1 - P_2 h_2)$
Fuel in thermal oil boiler (g_{2c}, l)	$g_{2c} = \frac{1}{n_2} P_3 h_3 c_3$
Diesel in gnerator set and loader (g_2, l)	$g_2 = \frac{1}{n_2} P_4 h_4 c_4 + P_5 h_5 c_5$
Waste products generated in UP 2 (r_2, kg)	$r_2 = \frac{1}{1+\varepsilon} (\sum (m_i + m_j + m_k) - 1000$

APPENDIX

Tabla A2: Calculation models for inputs and outputs of UP-1, UP-2 and UP-3

PU 3: TRANSPORTATION AND LAYDOWN OF BITUMINOUS MIXTURE	
Total diesel (g_3, l)	$g_3 = g_{31} + g_{32} + g_{33}$
Diesel in bituminous mixture trasporation (g_{31}, l)	$g_{31} = 0{,}8(1+\varepsilon)\, c_t\, d$
Diesel in laydown equipment (g_{32}, l)	$g_{32} = \frac{c_m}{n_3} \sum_{i=6}^{14} P_i h_i$
Diesel in milling and brushing machinery g_{33}, l)	$g_{33} = \frac{c_m}{n_3} \sum_{i=15}^{16} P_i h_i$
Waste products generated in UP 3 (r_3, kg)	$r_2 = 1000\,\varepsilon$

APPENDIX

Tabla A3: Symbols and values used

SYMBOL	DESCRIPTION	OBSERVATIONS
p_1, p_2, p_3, p_4	Ratio of each aggregate, by weight of blended aggregate	Independent variables
p_5	Ratio of mineral filler by weight of blended aggregate	Independent variable
b_t	Ratio of total bitumen by weight of mix	Independent variable
μ	Ratio of losses in transporting and stockpilling of raw materials	Independent variable
ε	Ratio of losses of bituminous mixture in cuts, joints and excess of laydowned material	Independent variable
b_n	Ratio of new bitumen added by weight of mix	Dependent variable
b_r	Ratio of residual binder in the bituminous emulsion by weight of emulsion	Dependent variable
p_6, p_8	Ratios of RAP and additives by weight of mix	Independent variables
p_7	Ratio of sufactants or viscosity reducers by weight of bitumen added	Dependent variable
p_9	Ratio of added bitumen by weight of mix	Dependent variable
c_t	Average diessel consumption of transporting vehicles, in l/100km	Dependent variable, according Euro level
d_i	Transport distances to the asphalt facility of aggregates, filler, RAP, additives and bituminous binder (km)	Independent variables
LCV_f	Low calorific value (kJ/kg)	Dependent variable, according fuel type

APPENDIX

Tabla A3: Symbols and values used

SYMBOL	DESCRIPTION	OBSERVATIONS
T_{MB}	Mix temperature at discharge of asphalt plant (ºC)	Independent variable
T_i	Temperatures in stockpiles of the bituminous mixture components (ºC)	Independent variables
T_a	Ambient temperature (ºC)	Independent variable
T_e	Average temperature of water vaporization (ºC)	Independent variable. Default value T_e=90º C
T_h	Temperature of exhaust gases (ºC)	Independent variable. Default value T_e=135º C
T_1	Inner temperature for calculating radiation and conduction heat losses (ºC)	Independent variable. Default value $T_1=T_{MB}$
T_2	External temperature for calculating radiation and conduction heat losses (ºC)	Independent variable. Default value $T_2=T_a$
CE_i, CE_w CE_v. E_W	Caloric constants	According table A.3
w_i	Water content of bituminous mixtures components expressed as percentatge by weight of dry mass	Independent variables
a	Ratio of excess air by stoichiometric air.	Independent variable. Default values A.4
a_{es}	Stoichiometric air required for combustion	Dependent variable. According table A.5
j	Ratio of leakage air by weight of stoichiometric air + excess air	Independent variable. Default values j=5%
k_1	Coefficient expressing the losses of heat by radiation	Independent variable. Default values k_1=0
k_2	Coefficient expressing the losses of heat by conduction.	Independent variable. Default values k_2=0,00075 ºK^{-1}
m_c	Equivalent mass of steel for calculating the energy used in heating the asphalt plant every start-stop cycle	Independent variable. Default values according A.6
d	Transport distances from the asphalt facility to the site (km)	Independent variable

APPENDIX

Tabla A3: Symbols and values used

SÍMBOL	DESCRIPCIÓ	OBSERVACIONS
P_1	Potència dels motors elèctrics de la central	Variable independent. Per defecte, valors taula A.6
P_2	Potència del sistema d'escalfament elèctric	Variable independent. Per defecte, valors taula A.6
P_3	Potència de la caldera de fluid tèrmic	Variable independent. Per defecte, valors taula A.6
P_4	Potència del grup electrègen	Variable independent. Per defecte, valors taula A.6
P_5	Potència de la pala carregadora	Funció del model seleccionat
P_i	Potència de les màquines d'estès i compactació (i=6 a 14)	Funció del model seleccionat
P_i	Potència de les màquines de fresat i escombrat (i=16 a 16)	Funció del model seleccionat
h_1	Hores diàries de funcionament de la central de fabricació	Variable independent
h_2	Hores diàries de funcionament del sistema elèctric d'escalfament de lligants	Variable independent
h_3	Hores diàries de funcionament de la caldera de fluid tèrmic	Variable independent
h_4	Hores diàries de funcionament del grup electrògen	Variable independent, per defecte, $h_3=h_1$
h_5	Hores diàries de funcionament de la pala carregadora	Variable independent, per defecte, $h_5=h_1$
h_i	Hores diàries de funcionament de l'equip d'estés i compactació (i=6 a 14)	Variables independents, per defecte, $h_6=h_7=...=h_{14}$
h_i	Hores diàries de funcionament de l'equip fresat i escombrat (i=15 a 16)	Variables independents
n_1	Producció diària de la central de fabricació (t)	Variable independent
n_2	Aturades diàries de la central (ud)	Variable independent
n_3	Producció diària de l'equip de posada en obra (t)	Variable independent

APPENDIX

Tabla A4: Caloric constants

SYMBOL	MAGNITUDE	VALUE	UD
CE_W	Specific heat of water (in liquid form)	4,184	kJ/k·º K
CE_v	Specific heat of water (in steam form)	2,032	kJ/k·º K
E_W	Heat of vaporization of water	2,25	MJ/k·º K
$CE_{1-5(n)}$	Specific heat of natural and recycled aggregates	0,835	kJ/k·º K
$CE_{1-4(s)}$	Specific heat of steel slag aggregates	0,78	kJ/k·º K
CE_b	Specific heat of bitumen	2,093	kJ/k·º K
CE_a	Specific heat of air	1,012	kJ/k·º K
CE_{CO2}	Specific heat of CO_2	0,839	kJ/k·º K
CE_{N2}	Specific heat of N_2	1,04	kJ/k·º K
CE_S	Specific heat of steel	0,447	kJ/k·º K

APÉNDICE

Tabla A5: Default values of variables P_1, P_2, P_3, P_4 and m_c

CAPACITY	ELECTRIC POWER		TERMAL OIL	GENERATOR	MASS OF STEEL
	ENGINES, P_1	HEATER, P_2	BOILER, P_3	SET, P_4	EQUIVAL., m_c
160 t/h	200 kW	180 kW	400 kW	400 kW	80.000 kg
180 t/h	240 kW	180 kW	480 kW	480 kW	90.000 kg
200 t/h	280 kW	240 kW	560 kW	560 kW	100.000 kg
220 t/h	320 kW	240 kW	640 kW	640 kW	110.000 kg
250 t/h	360 kW	280 kW	720 kW	720 kW	125.000 kg
280 t/h	400 kW	280 kW	800 kW	800 kW	140.000 kg
300 t/h	440 kW	320 kW	880 kW	880 kW	150.000 kg
360 t/h	480 kW	320 kW	960 kW	960 kW	180.000 kg

APPENDIX

Tabla A6: Low calorific value (LCV), stoichiometric air (a_{es}), constituents of the exhaust gas and excess air (α), default values.

COMBUSTIBLE	LCV (MJ/kg)	a_{es} (kg/kg)	CO_2	H_2O	N_2	a
Heavy fuel oil	40,5	13,31	21,70%	6,50%	71,80%	50%
Diesel	42,2	14,98	20,79%	7,45%	71,76%	30%
Natural Gas	48,28	16,37	15,02%	11,81%	73,17%	20%

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Any suggestion, indication or query related to its operation and use can be made at the email address: ecco2@arno.es

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