

# A Practice for the Application of Waste in Road Asphalt Pavements in an Eco-Friendly Way

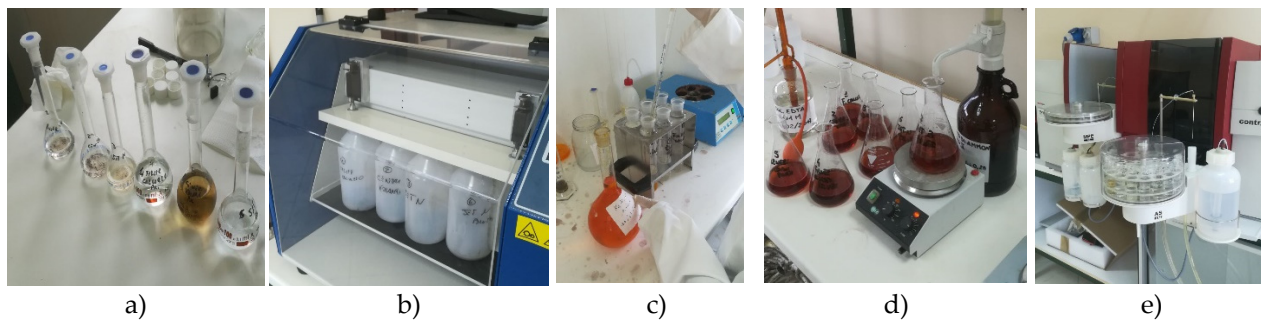
Francesca Russo, Cristina Oreto \* and Rosa Veropalumbo

Department of Civil, Construction and Environmental Engineering,  
University of Naples Federico II, Via Claudio 21, 80125 Naples, Italy;  
francesca.russo2@unina.it (F.R.); rosa.veropalumbo@unina.it (R.V.)

\* Correspondence: cristina.oreto@unina.it; Tel.: +39-0817683372

## Supplementary Materials

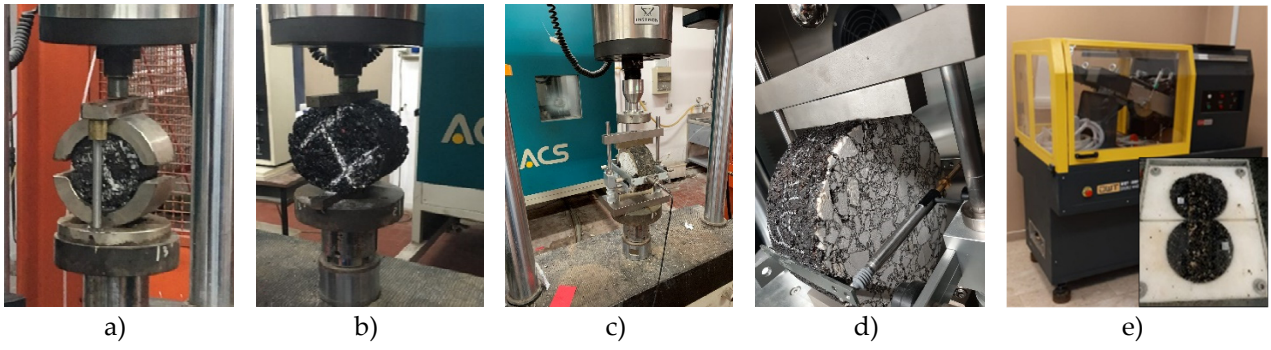
- **Fig. S1** Leaching test: a) sample mineralisation, b) stirring samples, c) making samples for COD investigation, d) titration for COD investigation and e) plasma optical emission spectrometry for the detection of metals
- **Table S1** Waste characterisation: a) leaching test results vs M.D. 05/02/1998, b) mechanical properties
- **Fig. S2** Testing equipment for a) Marshall test, b) ITS, c) ITSM, d) Fatigue test and e) wheel tracking test
- **Table S2** Normalized engineering performance and environmental indicators for matrix N1 for binder course and N2 for base layer
- **Table S3** Percentage weight assigned to each indicator for the initial weight configuration and the additional 24 weight configurations of sensitivity analysis
- **Fig. S3** Flowchart: unit processes of the life cycle of i) hot asphalt solutions and ii) cold in-place recycled asphalt mixtures



**Fig. S1** Leaching test : a) sample mineralisation, b) stirring samples, c) making samples for COD investigation, d) titration for COD investigation and e) plasma optical emission spectrometry for the detection of metals

**Table S1.** Waste Characterisation: a) leaching test results vs M.D. 05/02/1998, b) mechanical properties

| a)                         |      |           |        |        |        |                                 |
|----------------------------|------|-----------|--------|--------|--------|---------------------------------|
| Parameters                 | Unit | CDW       | JGW    | FA     | RAP    | Limits of<br>M.D:<br>05/02/1998 |
| Mercury                    | mg/l | <0.001    | <0.001 | <0.001 | <0.001 | 0.001                           |
| Arsenic                    | mg/l | <0.01     | <0.01  | <0.01  | <0.01  | 0.05                            |
| Barium                     | mg/l | <0.01     | <0.01  | <0.01  | <0.01  | 1                               |
| Cadmium                    | mg/l | <0.001    | <0.001 | <0.001 | <0.001 | 0.005                           |
| Cobalt                     | µg/l | <0.01     | <0.01  | <0.01  | <0.01  | 0.25                            |
| Chromium<br>total          | mg/l | <0.01     | <0.01  | <0.01  | <0.01  | 0.05                            |
| Nickel                     | mg/l | <0.01     | <0.01  | <0.01  | <0.01  | 0.01                            |
| Lead                       | mg/l | <0.01     | <0.01  | <0.01  | <0.01  | 0.05                            |
| Copper                     | mg/l | <0.01     | <0.01  | <0.01  | <0.01  | 0.05                            |
| Vanadium                   | µg/l | <0.01     | <0.01  | <0.01  | <0.01  | 0.25                            |
| Zinc                       | mg/l | 0.37      | 0.52   | 0.86   | <0.01  | 3                               |
| Asbestos                   | mg/l | <0.01     | <0.01  | <0.01  | <0.01  | 30                              |
| Selenium                   | mg/l | <0.01     | <0.01  | <0.01  | <0.01  | 0.01                            |
| Beryllium                  | µg/l | <0.01     | <0.01  | <0.01  | <0.01  | 10                              |
| Chloride                   | mg/l | 65.78     | 53.17  | 77.36  | 16.30  | 100                             |
| Nitrate                    | mg/l | 0.10      | 0.09   | 0.15   | 0.05   | 50                              |
| Fluoride                   | mg/l | <0.01     | <0.01  | <0.01  | 0.52   | 1.5                             |
| Cyanides                   | mg/l | <0.01     | <0.01  | <0.01  | <0.01  | 0.05                            |
| Sulphate                   | mg/l | 6.33      | 21.6   | 36.59  | 7.45   | 250                             |
| pH                         | -    | 5.02      | 10.92  | 6.05   | 6.95   | 12                              |
| COD                        | mg/l | 10.3      | 6.8    | 7.99   | 25.5   | 30                              |
| b)                         |      |           |        |        |        |                                 |
| Properties                 |      | Limestone | CDW    | JGW    | FA     | RAP                             |
| LA (EN 1097-2)             |      | 16        | 18     | -      | -      | 24                              |
| Rigden Voids (EN 1097-4)   |      | 51.4      | -      | 53     | 48.1   | -                               |
| Sand Equivalent (EN 933-8) |      | 80        | -      | 60     | 96     | 71                              |



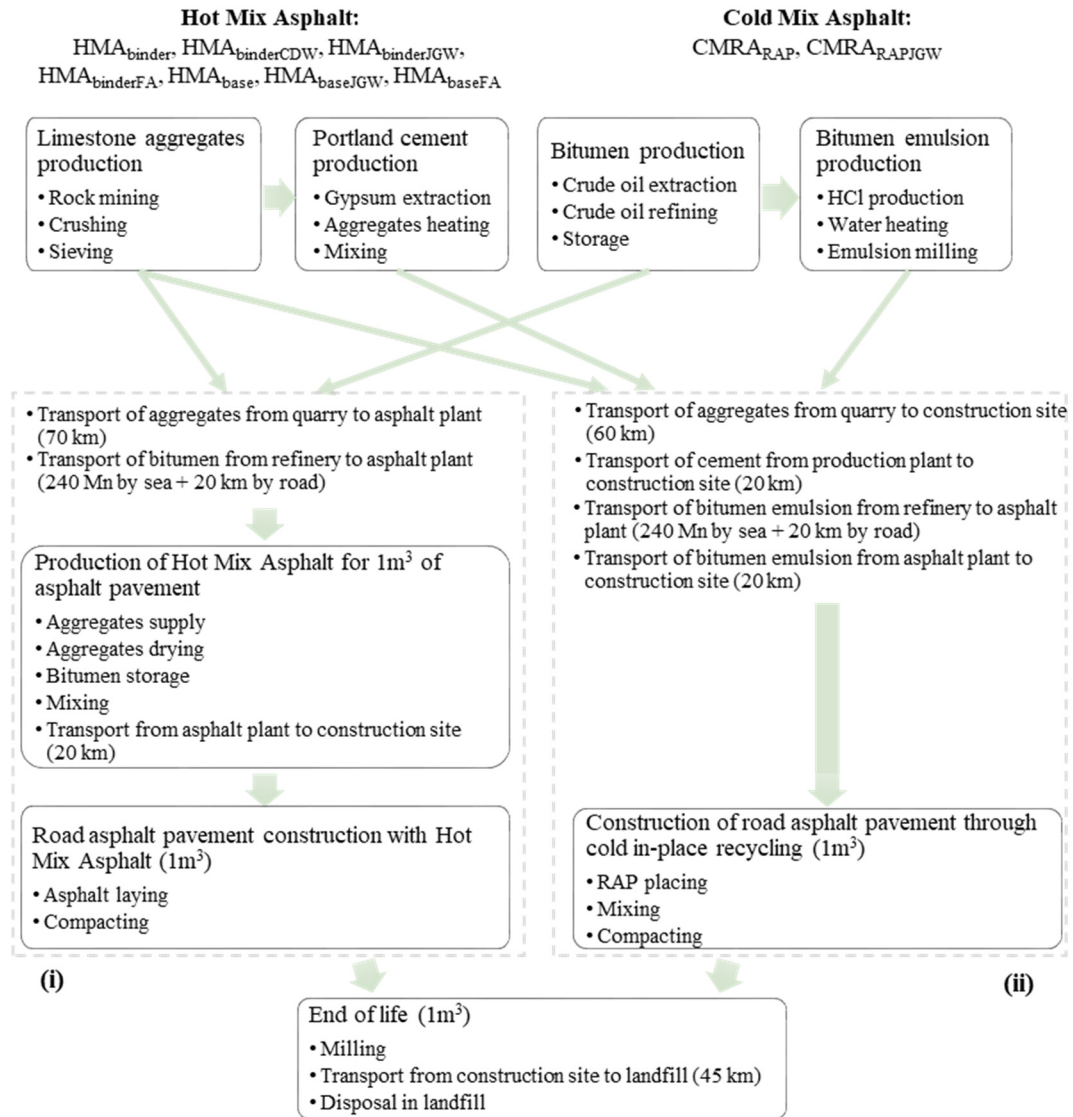
**Fig. S2** Testing equipment for a) Marshall test, b) ITS, c) ITSM, d) Fatigue test and e) wheel tracking test

**Table S2.** Normalized engineering performance and environmental indicators for matrix N<sub>1</sub> for binder course and N<sub>2</sub> for base layer

| Groups | Indicators | Binder layer (N <sub>1</sub> ) |                           |                           |                          | Base layer (N <sub>2</sub> ) |                         |                        |                         |                            |
|--------|------------|--------------------------------|---------------------------|---------------------------|--------------------------|------------------------------|-------------------------|------------------------|-------------------------|----------------------------|
|        |            | HMA <sub>binder</sub>          | HMA <sub>binder</sub> CDW | HMA <sub>binder</sub> JGW | HMA <sub>binder</sub> FA | HMA <sub>base</sub>          | HMA <sub>base</sub> JGW | HMA <sub>base</sub> FA | CMR <sub>base</sub> RAP | CMR <sub>base</sub> RAPJGW |
| HP     | S          | 0.47                           | 0.75                      | 1.00                      | 0.60                     | 0.78                         | 0.90                    | 0.83                   | 0.94                    | 1.00                       |
| HP     | MS         | 0.54                           | 0.69                      | 1.00                      | 0.59                     | 1.00                         | 0.94                    | 0.90                   | 0.83                    | 0.90                       |
| HP     | ITSM 40°C  | 0.63                           | 0.93                      | 1.00                      | 0.84                     | 0.59                         | 0.75                    | 0.69                   | 0.92                    | 1.00                       |
| HP     | RD         | 0.93                           | 0.97                      | 1.00                      | 0.94                     | 0.82                         | 0.83                    | 0.86                   | 0.93                    | 1.00                       |
| LP     | ITS        | 0.81                           | 0.69                      | 1.00                      | 0.97                     | 0.90                         | 1.00                    | 0.98                   | 0.89                    | 0.99                       |
| LP     | ITSM 10°C  | 0.86                           | 0.91                      | 0.97                      | 1.00                     | 0.82                         | 1.00                    | 0.95                   | 0.44                    | 0.47                       |
| LP     | ITSM 20°C  | 0.85                           | 0.79                      | 1.00                      | 0.97                     | 0.91                         | 1.00                    | 0.95                   | 0.34                    | 0.35                       |
| LP     | Nf         | 0.56                           | 0.50                      | 1.00                      | 0.86                     | 0.26                         | 1.00                    | 0.79                   | 0.08                    | 0.13                       |
| MP     | ITSR       | 0.91                           | 0.93                      | 1.00                      | 0.94                     | 0.96                         | 0.99                    | 1.00                   | 0.97                    | 0.98                       |
| EP     | GWP        | 0.97                           | 0.93                      | 0.97                      | 1.00                     | 0.75                         | 0.76                    | 0.80                   | 0.95                    | 1.00                       |
| EP     | ODP        | 1.00                           | 1.00                      | 1.00                      | 1.00                     | 0.58                         | 0.60                    | 0.63                   | 0.95                    | 1.00                       |
| EP     | IR         | 0.80                           | 1.00                      | 0.88                      | 0.87                     | 0.52                         | 0.55                    | 0.64                   | 0.88                    | 1.00                       |
| EP     | OFH        | 0.99                           | 0.88                      | 0.96                      | 1.00                     | 0.60                         | 0.60                    | 0.63                   | 1.00                    | 0.99                       |
| EP     | PM         | 0.99                           | 0.96                      | 0.99                      | 1.00                     | 0.13                         | 0.13                    | 0.13                   | 1.00                    | 1.00                       |
| EP     | OFT        | 0.98                           | 0.88                      | 0.97                      | 1.00                     | 0.57                         | 0.57                    | 0.59                   | 1.00                    | 0.99                       |
| EP     | A          | 0.96                           | 0.88                      | 0.95                      | 1.00                     | 0.67                         | 0.67                    | 0.72                   | 1.00                    | 0.98                       |
| EP     | FE         | 0.80                           | 1.00                      | 0.84                      | 0.84                     | 0.57                         | 0.59                    | 0.68                   | 0.87                    | 1.00                       |
| EP     | ME         | 1.00                           | 1.00                      | 1.00                      | 1.00                     | 0.99                         | 0.99                    | 1.00                   | 1.00                    | 1.00                       |
| EP     | T-ECO      | 0.98                           | 1.00                      | 0.98                      | 0.97                     | 0.53                         | 0.54                    | 0.54                   | 0.97                    | 1.00                       |
| EP     | F-ECO      | 0.98                           | 0.97                      | 1.00                      | 1.00                     | 0.75                         | 0.76                    | 0.78                   | 0.97                    | 1.00                       |
| EP     | M-ECO      | 0.98                           | 0.96                      | 1.00                      | 1.00                     | 0.73                         | 0.75                    | 0.77                   | 0.97                    | 1.00                       |
| EP     | CT         | 0.91                           | 1.00                      | 0.93                      | 0.93                     | 0.58                         | 0.60                    | 0.63                   | 0.94                    | 1.00                       |
| EP     | NCT        | 0.97                           | 0.83                      | 1.00                      | 1.00                     | 0.62                         | 0.63                    | 0.67                   | 0.94                    | 1.00                       |
| EP     | LU         | 0.89                           | 0.89                      | 1.00                      | 1.00                     | 0.76                         | 0.81                    | 0.94                   | 0.96                    | 1.00                       |
| EP     | MR         | 0.84                           | 1.00                      | 0.83                      | 0.82                     | 0.69                         | 0.70                    | 0.71                   | 0.86                    | 1.00                       |
| EP     | FR         | 0.96                           | 0.79                      | 0.87                      | 1.00                     | 0.57                         | 0.54                    | 0.59                   | 1.00                    | 0.83                       |
| EP     | W          | 0.74                           | 1.00                      | 0.83                      | 0.82                     | 0.50                         | 0.53                    | 0.58                   | 0.93                    | 1.00                       |

**Table S3.** Percentage weight assigned to each indicator for the initial weight configuration and the additional 24 weight configurations of sensitivity analysis

| Weight<br>configuratio<br>n | (0)<br>25% to<br>HP, LP,<br>MP, EHP | (1)<br>0%<br>HP | (2)<br>20<br>% | (3)<br>40<br>% | (4)<br>60%<br>HP | (5)<br>80<br>% | (6)<br>100<br>% | (7)<br>0%<br>LP | (8)<br>20%<br>LP | (9)<br>40<br>% | (10)<br>60<br>% | (11)<br>80%<br>LP | (12)<br>100<br>% | (13)<br>0%<br>EH | (14)<br>20%<br>EHP | (15)<br>40%<br>EHP | (16)<br>60%<br>EH | (17)<br>80%<br>EHP | (18)<br>100%<br>EHP | (19)<br>0%<br>MP | (20)<br>20%<br>MP | (21)<br>40%<br>MP | (22)<br>60%<br>MP | (23)<br>80%<br>MP | (24)<br>100%<br>MP |
|-----------------------------|-------------------------------------|-----------------|----------------|----------------|------------------|----------------|-----------------|-----------------|------------------|----------------|-----------------|-------------------|------------------|------------------|--------------------|--------------------|-------------------|--------------------|---------------------|------------------|-------------------|-------------------|-------------------|-------------------|--------------------|
| S                           | 6.3                                 | 0.0             | 5.0            | 10.0           | 15.0             | 20.0           | 25.0            | 8.3             | 6.7              | 5.0            | 3.3             | 1.7               | 0.0              | 8.3              | 6.7                | 5.0                | 3.3               | 1.7                | 0.0                 | 8.3              | 6.7               | 5.0               | 3.3               | 1.7               | 0.0                |
| MS                          | 6.3                                 | 0.0             | 5.0            | 10.0           | 15.0             | 20.0           | 25.0            | 8.3             | 6.7              | 5.0            | 3.3             | 1.7               | 0.0              | 8.3              | 6.7                | 5.0                | 3.3               | 1.7                | 0.0                 | 8.3              | 6.7               | 5.0               | 3.3               | 1.7               | 0.0                |
| ITSM 40°C                   | 6.3                                 | 0.0             | 5.0            | 10.0           | 15.0             | 20.0           | 25.0            | 8.3             | 6.7              | 5.0            | 3.3             | 1.7               | 0.0              | 8.3              | 6.7                | 5.0                | 3.3               | 1.7                | 0.0                 | 8.3              | 6.7               | 5.0               | 3.3               | 1.7               | 0.0                |
| RD                          | 6.3                                 | 0.0             | 5.0            | 10.0           | 15.0             | 20.0           | 25.0            | 8.3             | 6.7              | 5.0            | 3.3             | 1.7               | 0.0              | 8.3              | 6.7                | 5.0                | 3.3               | 1.7                | 0.0                 | 8.3              | 6.7               | 5.0               | 3.3               | 1.7               | 0.0                |
| ITSR                        | 25.0                                | 33.3            | 26.7           | 20.0           | 13.3             | 6.7            | 0.0             | 33.<br>3        | 26.7             | 20.0           | 13.3            | 6.7               | 0.0              | 33.3             | 26.7               | 20.0               | 13.3              | 6.7                | 0.0                 | 0.0              | 20.0              | 40.0              | 60.0              | 80.0              | 100.0              |
| RTI                         | 6.3                                 | 8.3             | 6.7            | 5.0            | 3.3              | 1.7            | 0.0             | 0.0             | 5.0              | 10.0           | 15.0            | 20.0              | 25.0             | 8.3              | 6.7                | 5.0                | 3.3               | 1.7                | 0.0                 | 8.3              | 6.7               | 5.0               | 3.3               | 1.7               | 0.0                |
| ITSM 10°C                   | 6.3                                 | 8.3             | 6.7            | 5.0            | 3.3              | 1.7            | 0.0             | 0.0             | 5.0              | 10.0           | 15.0            | 20.0              | 25.0             | 8.3              | 6.7                | 5.0                | 3.3               | 1.7                | 0.0                 | 8.3              | 6.7               | 5.0               | 3.3               | 1.7               | 0.0                |
| ITSM 20°C                   | 6.3                                 | 8.3             | 6.7            | 5.0            | 3.3              | 1.7            | 0.0             | 0.0             | 5.0              | 10.0           | 15.0            | 20.0              | 25.0             | 8.3              | 6.7                | 5.0                | 3.3               | 1.7                | 0.0                 | 8.3              | 6.7               | 5.0               | 3.3               | 1.7               | 0.0                |
| Nf                          | 6.3                                 | 8.3             | 6.7            | 5.0            | 3.3              | 1.7            | 0.0             | 0.0             | 5.0              | 10.0           | 15.0            | 20.0              | 25.0             | 8.3              | 6.7                | 5.0                | 3.3               | 1.7                | 0.0                 | 8.3              | 6.7               | 5.0               | 3.3               | 1.7               | 0.0                |
| GWP                         | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| ODP                         | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| IR                          | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| OFH                         | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| PM                          | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| OFT                         | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| A                           | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| FE                          | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| ME                          | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| T-ECO                       | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| F-ECO                       | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| M-ECO                       | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| CT                          | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| NCT                         | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| LU                          | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| MR                          | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| FR                          | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |
| W                           | 1.4                                 | 1.9             | 1.5            | 1.1            | 0.7              | 0.4            | 0.0             | 1.9             | 1.5              | 1.1            | 0.7             | 0.4               | 0.0              | 0.0              | 1.1                | 2.2                | 3.3               | 4.4                | 5.6                 | 1.9              | 1.5               | 1.1               | 0.7               | 0.4               | 0.0                |



**Fig. S3** Flowchart: unit processes of the life cycle of i) hot asphalt solutions and ii) cold in-place recycled asphalt mixtures