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KEEP THIS DOCUMENT SAFELY. YOU WILL BE REQUIRED TO PRODUCE THIS ACKNOWLEDGEMENT TO AN BORD PLEANALA IF YOU WISH TO APPEAL THE DECISION OF THE PLANNING AUTHORITY. IT IS THE ONLY FORM OF EVIDENCE WHICH WILL BE ACCEPTED BY AN BORD PLEANALA THAT A SUBMISSION OR OBSERVATION HAS BEEN MADE TO THE PLANNING AUTHORITY ON THE PLANNING APPLICATION.

Louth County Council

PLANNING APPLICATION REFERENCE No: 2360115

A submission/observation in writing, has been received from Eilís de Buitléir-Kearney on 23/06/2023 in relation to the above planning application.

The appropriate fee of €20 has been paid. (Fee not applicable to prescribed bodies)

The submission/observation is in accordance with the appropriate provisions of the Planning and Development Regulations 2001 and will be taken into account by the planning authority in its determination of the planning application.

Yours faithfully,  
Louth County Council

<b>AN BORD PLEANÁLA</b>	
LDG-	<u>070672-24</u>
ABP-	<u>319281-24</u>
15 MAR 2024	
Fee: €	<u>220.00</u> Type: <u>Cheque</u>
Time: <u>9:00</u>	By: <u>Reg Post</u>



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Louth County Council

PLANNING APPLICATION REFERENCE No: 2360115

A submission/observation in writing, has been received from Eilís de Buitléir-Kearney on 31/01/2024 in relation to the above planning application.

The appropriate fee of €20 has been paid. (Fee not applicable to prescribed bodies)

The submission/observation is in accordance with the appropriate provisions of the Planning and Development Regulations 2001 and will be taken into account by the planning authority in its determination of the planning application.

Yours faithfully,  
*Louth County Council*

The Secretary,  
An Bord Pleanála  
Dublin 1

**Re:** Third Party appeal against decision of Louth County Council

**Planning Authority Ref** 2360115

**Applicants for permission:** Hibernia Steel (Manufacturing) Limited

**Proposed Development:** Permission for development including: 1) Construction of approx. 5,719 sq.m. gross floor area (GFA) main building, to house hot dip metal galvanising plant, machinery and associated works and containing materials loading and unloading areas, chemicals storage areas, and staff welfare facilities. The main building will be in two main sections, both single storey, consisting of a northern section of approx. 2,636 sq.m. GFA and a southern section of approx. 2,404 sq.m. GFA, with maximum heights above finished ground levels of 17.30m and 14.55m, respectively, together with an approx. 679 sq.m. GFA two storey over basement section with a maximum height above finished ground level of 8.90m, adjoining the east of the northern section. The main building will include 4 no. emissions stacks located on the roof of the northern section of the building, each rising to a height of 2.7m above the maximum height of the northern section, and 1 no. emission vent located on the western side of the northern section of the building, at a height of 7.2m above finished ground level. 2) Construction of approx. 298 sq.m. GFA two storey office building to be located to north of main building, containing main reception area and general offices. 3) Provision of hardstanding area, processed and unprocessed materials storage areas and HGV/trailer parking spaces. 4) Provision of vehicular and pedestrian entrance. 5) Provision of 110 car parking spaces, including 7 EV charging points, and 20 bicycle spaces. 6) Provision of internal access road. 7) Provision of 2 no. weighbridges 8) Installation of 2 no. LPG tanks, 9) Construction of ESB substation within the main building. 10) Provision of bunded fuel storage area. 11) Provision of stormwater drainage and treatment infrastructure, including permeable paving, attenuation unit, infiltration area, rainwater harvesting tanks and ass. works. 12) Site landscaping works, including raised soil berm on part of the western boundary of the site with a max. ht. of approx. 3m above finished ground level. 13) Firewater retention infrastructure. 14) Provision of site security fencing

and entrance walls and gates. 15) Provision of signage. 16) Provision of site lighting. 17) And all ancillary site development works. An Environmental Impact Assessment Report (EIAR) and Natura Impact Statement (NIS) will be submitted with the application. The proposed development will require an Industrial Emissions (IE) Licence, under the EPA Act 1992, as amended

**Development address:** Mell, Drogheda, Co Louth  
**Date of decision** 19 February 2024 (Grant Permission)  
**Name of Appellant:** Sadbh de Buitléir-Kearney Eilís de Buitléir-Kearney and Eugene Kearney

**Address of Appellants:** The Orchard, Rosehall, Killineer Drogheda Co. Louth  
041 - 9845780

### **Introduction**

We wish to lodge an appeal against the decision of Louth County Council as described above. The decision was made on 19 February 2024 and therefore the appeal deadline is 19 March 2024, taking into account that the offices of An Bord Pleanála are closed on Monday 18 March, 2024

1. The appeal is accompanied by:
  - a. Appeal Form
  - b. All appendices listed on last page of this document.
  - c. Confirmation of submission to Louth County Council
  - d. Fee of €220

The grounds of appeal are set out below:

### **Carbon Footprint**

#### **Quotes taken From Report for Policy EE 63 (Carbon Footprint Calculations)**

“Hibernia Steel calculates an absolute emission summary based on a typical year of operation. Their calculation shows a level of 4695.508 tonnes per CO<sub>2</sub>e”

Hibernia states that these figures are generated with conservative estimates, and predict that this will be an overestimation of emission levels than may actually result.

They have a requirement to decrease embodied carbon in construction materials by 10% by 2025 and at least 30% by 2030.

There is a running theme through the Carbon Footprint report of promises of future improvements, with almost no detail or specific examples being given as to how these targets are going to be achieved, or what moves are being made at the outset of construction to reduce carbon footprint. In fact, all of these figures are from a predicted year of normal operation for the Galvanising facility, and do not involve any carbon impact generated by construction etc.

Part 3 of 3.2 Climate Action Plan states "Reduce fossil fuel demand by 7.5% by 2025 and 10% by 2030" The response from Louth County Council on this point in the planner's report suggests that Hibernia may reach this goal, in part, by switching from diesel powered forklifts to electric forklifts. We feel that it would be in the best environmental interests of the area to begin strong, by starting with electric vehicles rather than using their introduction as a relatively easy and artificial way to hit emission reduction targets.

### **Solar and Green Energy**

While it is heartening to see Hibernia's facility proposes to use solar energy, the solar panels have not been set up for maximum efficiency, and no attempt has been made to plan for seasonal storage of electricity. Despite the fact that Part 1 of 3.2 Climate Action Plan states "Increase total share of heating to carbon neutral to 50-55% by 2025, up to 70-75% by 2030", Hibernia have not planned for the storage of generated electricity, so they are not making the best use of their own proposed setup.

Louth County Council have suggested Hibernia can make their operation more environmentally friendly by gradually introducing Electric Forklifts, and buying green electricity. Electric forklifts should be introduced from the start, as they are current technology, more economical and safer due to fuel not being stored on-site, and that real efforts be made to reduce the carbon footprint. Not only is the use of electric Forklifts more environmentally beneficial, it is also economically beneficial as at the end of a 5-year period, Hibernia will have incurred lower costs. (See Appendix 6)

### **Project Splitting**

Work has commenced on the proposed IDA Business Park of which the Hibernia site forms part. We cannot locate a 7 day notice or a Commencement notice. Landscaping and retaining walls have already been put in place, as well as huge retention ponds.

Much of the development appears to hinge on the IDA's masterplan, which we have not been able to obtain from Louth County Council.

In fact, no Masterplan, as required, exists for the area surrounding the M1 retail park and the R132.

### **Effect on Residents**

The proposed building plans include 4 emissions stacks which are placed right up against the two residential homes sitting in a "cut-out" at one edge of the site.

While there has been consideration given to these two buildings in terms of lighting, no other thought seems to have been given regarding noise, smell or pollution.

A noise level of 55Db has been quoted for the operation of the galvanising facility, but this fails to take into account the noise caused by the flow of traffic into and out of the site, or the noise associated with loading and unloading large loads of metal; to say nothing of the disruption arrived by a high volume of staff coming and going.

It is telling that Hibernia has made no effort to produce photomontage showing the effect of their facility looking over these two homes; they should do so immediately.

In the event that this appeal is not allowed, Hibernia should be required to add a larger buffer of planted space between the edge of its facility and these affected homes, to protect them in terms of natural light, noise, etc.

Additionally, the proposed hours of operation will be very troublesome in a residential area; the facility should be restricted to an 8 am opening time, with a 9 am processing start time; with production ceasing at 5 pm so as to not cause interruption in day to day life. Additionally, residents should have a reprieve on weekends with hours of operation between 10 and 2 on Saturdays.

From personal experience working directly with this industry, it is "dirty, noisy and smelly", something which is at great odds with the pristine, pollution free view presented by Hibernia in their EIAR.

### **Alternative Sites**

Louth County council asked Hibernia to submit "a comprehensive study of reasonable alternatives which are outside the ownership of the applicant". Hibernia has not done so.

They have repeatedly asserted that they are submitting the minimum required in law. At point 2.2.2, Environmental Impact Report Assessment Document, they say "It is generally sufficient to provide a broad description of each main alternative and the key issue associated with each, showing how environmental considerations were taken into account in deciding on the selected option. A detailed assessment (or mini-EIA) is not required."

Rather than look at realistic alternatives in detail, they have re-examined the same three sites, two of which are not for sale, and one of which the applicant states is too small. A site that is too small for the facility cannot in any sense be called a reasonable alternative. It is beyond belief that there is only one site in the entirety of County Louth worth considering. It is of particular interest that, for

example, no attempt is made to assess the vacant serviced lands at Donore road. It is dismissed with “this location has been considered and is considered not to be a preferable selection to the application site.” No reasons are given. (See Appendix 1 and 2)

### **Dismissal of Observations**

Almost every observation made on this planning application, either initially or as part of FI has been noted by the planner, but none have been responded to, even when raising very serious questions, issues and observations.

### **Travel to Work Plan**

The travel to work plan is entirely aspirational, and fails to deal with very real issues, such as how one is to safely navigate one of the busiest roundabouts in Drogheda, where there are very poor cycle lanes and next to no footpath infrastructure, connecting to a road where people drive very fast. There is only one crossing point across four arms of the roundabout, which is quite unsafe, accompanied by a scrap of footpath, which swiftly gives way to grass.

### **Size of Lorries**

Extra-long lorries are entirely unsuitable for turning off into the site from the R132, and should be disallowed.

### **Environmental Impacts of Galvanising**

In summary, even a brief perusal of available literature shows that the idea of “clean” Hot-Dip galvanising is not so clear-cut as Hibernia would have us believe. While the articles included in the appendices talk about a potential cleaner future for Hot-Dip Galvanising, this future has yet to be realised, and it does not seem viable on an industrial scale in the safe, contained way Hibernia is implying.

The article: “A holistic framework for assessing hot-dip galvanizing process sustainability” states that while there may be improvements to the galvanising process, this may not be economically feasible to do so. (See Appendix 4)

Article: Carbon Footprint of the hot-dip galvanisation process using a life cycle assessment approach. Cleaner processes for Hot-Dip Galvanising are currently being investigated but are not fully viable yet. (See Appendix 5)

Additionally, the FI document provided by Mr Vaino-Matila goes into great detail showing the potential polluting impact of the galvanising facility upon the local water supply, which is of great concern to residents as many use their own wells; to say nothing of the use of nearby reservoirs for

Drogheda's water supply. (See Appendix 3)

**Conclusion:**

For all of the above reasons, we ask you to allow this appeal, and refuse planning permission. Should permission be granted, we would ask you to take our concerns into account.

Yours Sincerely,

Sadbh de Buitléir-Kearney, Eilís de Buitléir-Kearney, and Eugene Kearney.

## **List of Appendices**

1. The Orchard Original Planning Objection
2. The Orchard FI Reponse.
3. Thomas Vainio-Mattila FI Response.
4. A holistic framework for assessing hot-dip galvanizing process sustainability (Jose D. Hernández-Betancur, Hugo F. Hernández, Luz M. Ocampo-Carmona)
5. Carbon footprint of the hot-dip galvanisation process using a life cycle assessment approach (Andrea Arguillarena, María Margallo, Ane Urtiaga)
6. Locators' On The Electric Forklift vs Diesel Forklift Debate (<https://www.locators.co.uk/electric-forklift-vs-diesel-forklift/>)



**The Orchard,  
Killineer,  
Drogheda,  
A92R2DD.**

**To:** Louth County Council

**From:** Eilís de Buitléir-Kearney, Eugene Kearney & Sábh de Buitléir-Kearney

**Re:** Observation on Planning Application No 2360115

**Applicant:** Hibernia Steel (Manufacturing) Limited

**Proposed Development:**

Permission for development including: 1) Construction of approx. 5,719 sq.m. gross floor area (GFA) main building, to house hot dip metal galvanising plant, machinery and associated works and containing materials loading and unloading areas, chemicals storage areas, and staff welfare facilities. The main building will be in two main sections, both single storey, consisting of a northern section of approx. 2,636 sq.m. GFA and a southern section of approx. 2,404 sq.m. GFA, with maximum heights above finished ground levels of 17.30m and 14.55m, respectively, together with an approx. 679 sq.m. GFA two storey over basement section with a maximum height above finished ground level of 8.90m, adjoining the east of the northern section. The main building will include 4 no. emissions stacks located on the roof of the northern section of the building, each rising to a height of 2.7m above the maximum height of the northern section, and 1 no. emission vent located on the western side of the northern section of the building, at a height of 7.2m above finished ground level. 2) Construction of approx. 298 sq.m. GFA two storey office building to be located to north of main building, containing main reception area and general offices. 3) Provision of hardstanding area, processed and unprocessed materials storage areas and HGV/trailer parking spaces. 4) Provision of vehicular and pedestrian entrance. 5) Provision of 110 car parking spaces, including 7 EV charging points, and 20 bicycle spaces. 6) Provision of internal access road. 7) Provision of 2 no. weighbridges 8) Installation of 2 no. LPG tanks, 9) Construction of ESB substation within the main building. 10) Provision of bunded fuel storage area. 11) Provision of stormwater drainage and treatment infrastructure, including permeable paving, attenuation unit, infiltration area, rainwater harvesting tanks and ass. works. 12) Site landscaping works, including raised soil berm on part of the western boundary of the site with a max. ht. of approx. 3m above finished ground level. 13) Firewater retention infrastructure. 14) Provision of site security fencing and entrance walls and gates. 15) Provision of signage. 16) Provision of site lighting. 17) And all ancillary site development works. An Environmental Impact Assessment Report (EIAR) and Natura Impact Statement (NIS) will be submitted with the application. The proposed development will require an Industrial Emissions (IE) Licence, under the EPA Act 1992.

Dear Sir or Madam,

We wish to make the following observations on this proposed development.

• The address on the site notice is incorrect, and only specifies "Mell, Drogheda, Co. Louth" Mell is a townland, not an address.

• The Louth County Development Plan 2021-2027 states "The compatibility of a particular use or operation will be dependent on the nature of use/operations and surrounding uses in the area on which the development will be located." This application is clearly at odds with its surroundings and the orderly development of the area. The relationship between the site and the surrounding area has equal importance to the employment-generating zone. In this area there is absolutely no heavy industry and indeed very little industry at all.

Historically, what is now called the Drogheda North Business Park has been designated for startups, light industry and warehousing. This is what the County Councillors would have expected when they accepted the current County Development Plan.

No reasonable person reading the current or previous County Development Plans could have envisioned heavy industry being located in this site.

• Not all sensitive receptor locations are marked on the map submitted by the developer. In particular, Killineer House and Gardens and Field House Rosehall Lane are not listed as sensitive receptors and neither are the many other dwellings and business in the immediate area. They are clearly visible on the maps the developer has submitted.

• In addition Rosehall and Killineer Reservoirs are not listed as sensitive receptors which would be expected under best international practice. Neither are the many well and springs in the immediate area, including the 3 boreholes at Waterunder which as a group water scheme supply approximately 50 houses from Waterunder to Mell.

• The development will be situated over the Wilkinstown ground waterbody which already has a "Poor" chemical status and an overall status overall status of "Poor. It is also close to the Mell Stream which runs directly into the Boyne. An examination of reports by the EPA shows that the groundwater all Hot Dip Galvanising Plants in the country have increased levels of zinc and ammonia in the groundwater. None of these plants are sited between two reservoirs which are emergency water supply for a major town. The work currently being undertaken by Uisce Éireann on Rosehall, Killineer and Barnattin Reservoirs strongly suggests that these reservoirs will be brought back into use, especially in light of the additional five thousand houses being built along the Northern Cross Route.

• The Environmental Impact Assessment, Environmental Impact Report and Natura Impact Statement for the site are inadequate, having been undertaken in January, when many native species are dormant (such as frogs and hedgehogs).

• No animal was actually observed on the site, and yet 13 different species of mammal and amphibian have been sighted within metres of this site, including protected species such as pine martens and bats.

• The following list of species in the area has been compiled by the residents and is not exhaustive:

Bat, Common Frog, Field mouse, Grey Squirrel, Hedgehog, House mouse, Pine Martin, Pygmy Shrew, Rabbit, Brown Rat and Stoat.

- Only 10 species of birds had been mentioned, and yet 44 have been documented by residents. Again the list is not exhaustive:
  - Yellowhammer, Robin, Coot, Hooded Crow, Jackdaw, Magpie, Rook, Feral Pigeon, Rock Dove, Wood Pigeon, Dunnock, Bullfinch, Chaffinch, Greenfinch, Goldfinch, Mealy Redpoll, Siskin, Pheasant, Grey Heron, Kingfisher, Barn Owl, Buzzard, Kestrel, Sparrow Hawk, House Sparrow, Tree Sparrow, Staring, Swallow, House Martin, Mute Swan, Swift, Blackbird, Mistle Thrush, Song Thrush, Blue Tit, Coal Tit, Great Tit, Long-tailed Tit, Tree Creeper, Grey Wagtail, Pied Wagtail, Blackcap, Willow Warbler and Wren.
- Most of these birds have an orange status with Swift, Yellowhammer, Grey Wagtail, Kestrel, and Barn Owl having a red status. (Birds of Conservation Concern in Ireland 2020 - 2026. Gilbert G, Stanbury A & Lewis L) It is difficult to understand how so little wildlife was observed on the proposed development site, especially as we are up to our ears in most of the animals mentioned above, here at The Orchard and we are only meters from the site. Carrying the assessment out at the end of January makes it very difficult to identify wildlife on the site and accounts for some of the discrepancy. This discrepancy will have to be made good and a further EIA carried out at a more appropriate time of the year.
- We have lived at The Orchard for more than a quarter of a century and in that time have striven to live in an environmentally sustainable way as possible.
- We have a photovoltaic array on our roof of the maximum size allowed. We use a heat recovery system within the house. These measures reduced our use of heating oil by 80%.
- While we do not garden entirely organically, our use of weed killer is kept to an absolute minimum and is of the bee friendly variety.
- As the name suggests we have an orchard with in excess of forty apple trees, many of them heritage varieties. We also grow grapes, pears, plums, damsons, medlars, quinces, red and black currants, cherries, figs, raspberries, strawberries and rhubarb.
  - We have vegetable and herb gardens, where we grow old and rare varieties.
  - We have established a small woodland, with an emphasis on native species and underplanted with native bluebells, ferns of many varieties, wild onions etc.
  - We have planted thousands of bulbs both in the woodland and in the main orchard. This orchard is allowed to go to meadow grass when the bulbs are finished. The Small Orchard is underplanted with native wild flowers.
  - We have also planted dozens of highly scented old roses throughout the grounds.
  - In addition we have drastically reduced the amount of lawn and replaced it with native wild flowers. This is an ongoing process.
- The lawns, such as they are, are mown by a robotic lawnmower which uses rechargeable batteries and is set at a height which allows the lawns to flower. The first flowering is of buttercups and the current one is of clover.
- We installed a pond about a decade ago and have repeatedly successfully bred outdoor goldfish, which is a very rare achievement and is a reflection of the type of environment we have created.
- We have our own well and sewerage system.

- Despite being close to a main road, we have excellent air quality, as can be seen from the variety and quantity of lichen on our trees, stonework and fences.
- We are seriously concerned that this development will completely undermine the work of more than a quarter of a century.
- As we have one of the many wells in the area, we are very concerned that the groundwater will be contaminated, with consequential danger to both our own health and that of the fish. This point equally applies to the fish in Rosehall and Barnatin reservoirs. Looking at the EPA reports on Hot Dip Galvanising Plants this contamination is inevitable, even with all possible preventative measures being taken. It is not possible to comment on the process that will be used in the Hibernia plant as Hibernia has not said which in their planning application. This is another area in which the EIA and EIS are deficient and this must be rectified.
- Consideration has to be given to the reservoirs and the many wells and springs in the area, which are either not mentioned or briefly mentioned in passing.
- There is also the danger of air pollution from this plant.
  - "Zinc vapour has been known to cause metal fume fever. Symptoms of metal fume fever include fatigue, chills, muscle pain, fever, cough, and shortness of breath. Although metal fume fever is an occupational disease, Graham residents could feel some of the symptoms associated with it if they inhale too much contaminated air" ( Kelsey Behrens. Duke University Advisor: Beverly Kerr, Blue Ridge Environmental Defense League)
- 5,000 houses are under construction very near to this site as part of the Northern Cross Route. The reservoirs are likely to be brought back into use, as evidenced by ongoing works by Uisce Éireann, to serve as water supplies for the Drogheda area. The danger of pollution of these water sources has to be considered. There is a problem with heavy metals collecting on the ground at hot dip galvanising plants.
- Exceptionally heavy rain, which is becoming more common with climate change will cause further threat to the watercourses.
- The rigour with which the Environmental Protection Agency monitors hot dip galvanising plants is indicative of how dangerous they are and all these plants are smaller than proposed plant. Not only are the Reservoirs ignored as sensitive receptors; they should be listed as such in line with best international practice, but Rosehall Reservoir is listed as "Sewerage Plant Complex". Even the briefest of inspection would have shown that it is no such thing but a small lake filled with coarse fish, which is a resource not only for local fishermen but also for the Tourism fishing industry.
- The site is adjacent to an aquifer, with the obvious dangers of pollution. It The proposed plant is directly across the road from Rosehall Reservoir, and lands that are zoned for Tourism and Leisure. The North Drogheda Business Park extends up as far as the Killineer Reservoir.
- The Boyne Valley area is working towards becoming a 'Green destination' attracting EcoTourism with the Boyne Camino, Greenways etc. Setting a heavy industry in the area will undercut the policy of developing EcoTourism in the area and ultimately result in fewer jobs in the area.
- The area to to the east of the site and south of the Rosehall Reservoir is Zoned for Tourism and Leisure. It's capacity to attract tourism and leisure projects would be

completely undermined by siting a heavy industry directly adjacent to the Zone and undermine the County Development Plan.

- Just two examples of Tourism and Leisure in the immediate area are fishing at Rosehall and Killineer Reservoirs and the facilities at Killineer House and Gardens. The County Development Plan clearly envisions these assets being built upon.
- Alternative sites have not been scouted with much rigour, and no evidence has been provided to prove that this is the best site for this industrial development. The process for evaluating alternative sites was seriously deficient and did not involve any public consultation. The reasons given for rejecting the other three sites were, (1) The landowner did not wish to sell; no evidence is offered of this. (2) A price could not be agreed; no evidence is offered to back up this statement and (3) We choose this site rather than the IDA Business and Technology Park. Again, no evidence is offered as to why the current site is more suitable. On visiting both the IDA Business Park and Technology Park and the area around Tom Roes Point I observed that a large sites are for sale.
- There are at least three brownfield sites in Drogheda. No evidence has been produced as to why the sites they considered were deemed to be unsuitable, and why the other brownfield sites were not considered. Again, land is for sale at Tom Roes Point and has not been considered.
- The rationale for selecting the current site seems to be. The IDA said we could and it's near good roads. The former is not a planning consideration and a site specific justification needs a great deal more than being near good roads.
- The volume of traffic to and from the site will need to be examined for the entire Business Park, not just the Hibernia plant, with particular emphasis on the volume of traffic leaving the site at the end of the work day. Not to do so is project splitting. A considerable amount of this traffic will be cutting across oncoming traffic on a part of the road with bad bends which has a history of accidents and deaths. In addition, the size of loads likely to be associated with this plant will be so large as to require special permission to use the public roads. The plant will be capable of galvanising items 27-28m in length an the maximum load that can be transported without a special license is 12m with a 3m overhang.
- There is insufficient road infrastructure and street lighting for access to the site.
- The Road is on a bad bend and there isn't the width in the road to allow for safe access to the site. There is hard shoulder on one side of the road and no cycle lane, despite the exception that people will arrive at the site by bicycle.
- Section 5.38 to 5.44 of the Planning Report (Stephen Peck, Chartered Town Planner) states that infrastructure works will be carried out by IDA Ireland which are yet agreed.
- Without this infrastructural work it would be impossible for the plant to operate. There is no evidence or agreement that such work will be carried out.
- The proposed development proposes 110 car parking spaces, including 7 EV Charging Points and 2 Disabled Parking spaces. The dimensions of the parking spaces is not stated.
- The Louth County Development Plan 2021-2027 sets out the following requirements; for 110 parking spaces there should be 22 EV charging points, rather than the 7

proposed and there should be 6 Disabled Parking Spaces, rather than the six proposed.

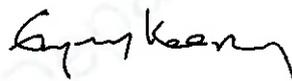
- The facility, should it be built, should have to use clean energy sources, electricity, and should be required to put solar panels on the roofs.
- At present, two houses are boxed in very closely by the site; leaving them surrounded on three sides. This plant could have been placed anywhere on the Drogheda North Business Park. Instead it is sited in a way that destroys the residential amenity of two family homes and will cause them to be significantly devalued. This is sufficient reason alone to refuse planning permission, See Louth County Council 07 1999 (Terry King Quarry) and An Bord Pleanála decision APB-308555-20 Kildare County Council.
- From a personal point of view, I find the decision to seek planning permission here as inappropriate and cruel and is the cause of significant distress, not only to the families involved but, to the wider community which cannot understand how people can be treated like this, not only by Hibernia but also with the backing of the IFA and Enterprise Ireland. It is reasonable to expect the highest standards from state sponsored bodies, a standard which is not evident here.

Neither the IDA nor Enterprise Ireland have any greater standing in planning law than the ordinary citizen. Their backing of such an unsuitable project is difficult to understand, particularly as it will destroy the residential amenity of the family homes, in the area, particularly on Rosehall Lane and Drakerath Lane, a number of which are almost three hundred years old. Again I refer to Louth CoCouncil 07 1999 (Terry King Quarry) and An Bord Pleanála decision APB-308555-20 Kildare County Council.

Eilís de Buitléir-Kearney

Eugene Kearney

Sadbh de Buitléir-Kearney



The Orchard,  
Rosehall,  
Killineer,  
Drogheda, Co. Louth

RECEIVED: 23/01/2024

Planning Section,  
Louth County Council,  
Town Hall,  
Crowe St.,  
Dundalk,  
Co. Louth

24th January 2024.

**Re: Planning Reference No. 2360115**  
**Hibernia Steel (Manufacturing) Limited.**

This objection is to be read in conjunction with our original planning objection.

1. Louth County council asked Hibernia to submit “a comprehensive study of reasonable alternatives which are outside the ownership of the applicant”. Hibernia has not done so.
  - a. They have repeatedly asserted that they are submitting the minimum required in law. At point 2.2.2, Environmental Impact Report Assessment Document, they say “It is generally sufficient to provide a broad description of each main alternative and the key issue associated with each, showing how environmental considerations were taken into account in deciding on the selected option. A detailed assessment (or mini-EIA) is not required.”
  - b. Rather than look at realistic alternatives in detail, they have re-examined the same three sites, two of which are not for sale, and one of which the applicant states is too small. A site that is too small for the facility cannot in any sense be called a reasonable alternative. It is beyond belief that there is only one site in the entirety of County Louth worth considering. It is of particular interest that, for example, no attempt is made to assess the vacant serviced lands at Donore road. It is dismissed with “this location has been considered and is considered not to be a

preferable selection to the application site.” No reasons are given. Other sites are dismissed just as summarily. Equal weight is not given to environmental/historical concerns across all sites. If the site is not the IDA Business Park, environmental, archeological and historical issues are deemed to be of major concern, but where these issues arise at the proposed site, they are minimised. Obviously the point of performing a comparison is to accurately assess the proposed development’s impact across all sites. To lessen one potential impact on a site because it is a favourite renders the whole comparison invalid.

- c. The applicants have mentioned that a significant amount of the steel will be prepared in Grangegeeth and transported to the Hot-Dip Galvanising plant. This is not mentioned at all in the original information supplied, and has not been assessed.
- d. Hibernia have stated how unsuitable the area around Grangegeeth is for the level of traffic that would be generated by a hot-dip galvanising plant, yet the very significant increase in traffic between Grangegeeth and the Hot-Dip Galvanising Plant at the IDA Business Park is barely mentioned, is used mostly to eliminate other sites, and has not been assessed. In the absence of this assessment, planning permission should be refused.
- e. We are not advocating for any particular site in our comments on the examination of alternative sites; rather we are pointing out the contradictions and shortcomings in the analysis carried out. The applicant has dismissed the area of Tom Roe’s Point as an alternative as it would take 3 to 4 minutes longer to get there than the North Road. No basis is given for this figure of 20 minutes drive. Depending what time of day one is driving at, this time could be much greater or lesser than the estimate. Using Google Maps, which gives similar results to those quoted in the FI response, to estimate how long it would take to drive from The Orchard to St Peter’s Church on West Street is given an estimated journey time of 10 minutes. This distance can be travelled in 6 - 7 minutes during light daytime traffic, but can, and has, taken up to 30 minutes during heavy traffic “rush hour” periods. We solve this problem by not travelling during “rush hour” if at all possible. The same option is open to Hibernia. How this compares to the hours in which materials are likely to be transported does not appear to have been considered. This is not significant enough to deem a site unacceptable. It is yet one more new criteria introduced to justify the use of the IDA Business Park site. No mention is made of the time it will take to deliver the galvanised products to their end destination, which might be even more significant.

- f. I do not propose to go through all the alternative sites mentioned, however briefly, by the applicant, other than to point out that they do not meet the Council's requirement to comprehensively study alternative sites. Even the current site has been poorly evaluated, and does not meet the legislative requirements.
2. The workplace travel plan is almost entirely aspirational, has not been future-proofed, and lacks foresight and imagination. There is a major problem walking to the site, which is already hazardous. Crossing the junction at the Rosehall Roundabout, where there is no footpath, will become more so when the Northern Cross Route opens shortly; though even as it stands, it is neither a safe nor pleasant walk. This will continue to discourage walking to work from Drogheda, and will only serve to increase car traffic volumes unless a safe and reasonable alternative is provided. No suggestion is made as to how this crossing might be made safe.
- A shared electric bus would certainly be more likely to encourage people not to take their cars to work, as opposed to being able to sign an umbrella out if it is raining.
  - The applicant does not seem to have consulted any transport companies in drawing up their workplace travel plan.
  - The applicant has made no suggestion as to how the safety of pedestrians might be improved.
3. Even the briefest online search will show changing the orientation of the building to be south-facing will allow for an up to 20% increase in the efficiency of the photovoltaic panels. This is easy to change at this early design stage, but is impossible once construction has begun. The orientation of this building, and indeed all buildings, should be such as to allow for maximum electricity generation, especially in light of the dire climate forecasts we have seen recently. As there is no proposal to do this and as it may not be possible on the current site, Planning Permission should be refused.
- The applicant is extraordinarily unambitious in their carbon emission reduction targets. Clearly it is not an area that interests them. Given the effects of climate change we have seen and experienced in the last year alone, it is imperative that not only Hibernia Steel but all of us do everything possible to mitigate our impact on the environment. It is essential that one considers not just the effect that this plant will have on the environment today, but in twenty years time.
  - The applicant proposes that all of the forklift trucks will run on diesel. This necessitates the storing of diesel on-site, which is a hazard and contributes to the on-site carbon emissions. Electric forklift trucks are already in use in the immediate area. If planning permission is granted,

the applicant should be refused permission to store diesel on-site, and be required to use electric forklift trucks. We presume the mention of 100 forklift trucks in the documentation is a typographical error.

- c. "It is the policy (IU 65) of the Louth County Development Plan 2021-2027 (as varied) to encourage and support the development of solar energy infrastructure for on-site energy use, including solar PV, solar thermal, and seasonal storage tech. The applicant is requested to document compliance with this policy requirement." This policy requirement has not been complied with, as storage is seen as something to be pushed as far out as possible, rather than be an integral part of the project from the start.
4. Hibernia Steel is not a steel manufacturing facility; our understanding is that they buy and cut steel to sell on. They will be relying on buying in expertise to run a hot-dip galvanising plant.
5. Given what appears to be extreme reluctance to incur expenditure in relation to this application, either from the point of view of the initial EIAR, a robust response to the Further Information Request or expenditure which would make the plant more carbon neutral, we have grave concerns about Hibernia's lack of experience in this area, appesantire reluctance to invest in preparation for the project and fear there may be a tendency to cut corners.
6. No mention is made of the inevitable ground pollution caused by Hot-Dip Galvanising, as is evidenced by EPA reports quoted elsewhere in objections to this proposal.
7. We note that without this plant being built, it is expected that emission levels in this area would improve in the future. The company asserts that the proposed galvanising method "will be a market leader in terms of embracing the latest technologies and systems in terms of fuel consumption and energy efficiency". No detail is offered or studies quoted.
  - a. Rather than have an aspiration to have a lower carbon footprint at some point in the future, this plant and any plant should it be given planning permission, should have to have the lowest carbon footprint possible from the start.
  - b. Practical and easy steps to lower the carbon footprint would be to
    - i. Provide an electric shuttle bus to collect people in the local area and the train and bus stations.
    - ii. To use electric forklift trucks in place of diesel.
    - iii. To reorient the solar panels for maximum solar gain. The possibility of using a heat pump should be explored.
  - c. Hibernia do not seem to have looked into any form of carbon emissions reduction that was not mentioned directly in observations on their

planning application. They do not appear to have independently researched the area of alternative technology and carbon reduction. This deficit could have serious implications for the impacts of the proposed development.

8. The IDA Masterplan has to form an integral part of this submission, especially in relation to access to the site. The considerable confusion as to what is or is not in the Masterplan will have to be resolved with documentation rather than a mere statement that there is a mistake in the Masterplan submitted by the IDA under planning reference 2360388. No detail in regards to access to the site etc, which should be covered in the Masterplan, is even mentioned. The Masterplan itself is mentioned, and then is entirely ignored. In the absence of the required details which would be expected to be associated with the Masterplan, planning permission should be refused.
9. The land needed to make infrastructural changes to the R132 is owned by four landowners, in addition to Louth County Council. I am unsure as to the ownership of Rosehall Reservoir. Part of the land in private ownership, which we own, forms a steep bank to the road and contains a sewage treatment system which would be seriously affected, and would have to be relocated, were the land to be acquired for a road upgrade. This would necessitate doing damage to the woodland we have planted. As the owners of this land, we have no interest in selling it, and the compulsory purchase process, which would be necessary to facilitate the road upgrade to make access to the site safe, would take many years, and make it impossible for the plant to operate in the short to medium term. Specifically the road upgrades would be needed to deal with the extraordinarily long loads mentioned in our previous submission, which double-dipping would generate. The application is therefore premature.
10. The land to the northwest, abutting our property on the left hand side is owned by Louth County Council, which would be required for improvement of the road. It is showing significant signs of slippage, which brings into question future road safety.
11. All maps are, by definition, out of date; however those used in this planning objection are critically so. When it comes to sensitive receptors, for example, an entire house is missing from the map. It was recently completed, but has been under construction since 2021. More than a simple desk exercise is necessary here, and this shows a grave lack of research and knowledge of the area surrounding the site.
12. The habitat survey is still too restrictive, and we ask that this be properly carried out in accordance with the legislation; and we refer back to the comments in our previous submission, noting that the survey was carried out

- during a period of the year in which most wildlife is hibernating or elsewhere due to migration.
13. The photo montages show how visually intrusive the building will be; not only in the immediate area, but also from Oldbridge and other sensitive parts of the landscape, which is one of the most significant in the country and widely promoted as a tourist resource.
  14. In the Planners Report Ref:07 1999, the road R132, along which this development is proposed is “deemed to be of insufficient width and alignment for regular heavy goods and vehicle use”.
  15. Hibernia maintains that LPG “was deemed more sustainable than electrical options”. In some circumstances this might be true, but it depends on many variables. Hibernia have not explained how they came to this conclusion and offered no evidence as to its veracity. If Hibernia wishes to use LPG, some actual scientific evidence is required and would be most helpful. In its absence Hibernia should be required to use electricity to power their machinery.
  16. Bibliographies have been included at the ends of sections. They are not referenced within the body of the application documents, for the most part, so it is impossible to know whether any of the documents mentioned are relevant or not.

On all of these grounds, we think planning permission should be refused.  
As this is a response to a further information request, no payment is required.

Eilis de Buitléir-Kearney, Sadbh de Buitléir-Kearney, Eugene Kearney.

Niamh and Thomas Vainio-Mattila  
Kearneys Lane  
Killineer  
Co Louth

Killineer, 25<sup>th</sup> January 2024

Planning Department  
Louth County Council  
Millenium Centre  
Dundalk  
Co Louth

**Re: Objection to Further Information in Relation to Planning Application File Number 2360115 - Hibernia Steel (Manufacturing) Limited**

To Whom It May Concern,

We are writing to you in relation to **Further Environmental Information** (FI) received by Louth County Council on the 4<sup>th</sup> of December 2023 with respect to Planning Application File Number 2360115, submitted by Boylan Consulting on behalf of **Hibernia Steel (Manufacturing) Limited**. The initial planning application was received by the Louth County Council Planning Department on the 22<sup>nd</sup> of May 2023.

The initial planning application was submitted in relation to a proposed **large scale, heavy industry, hot dip metal galvanising plant** at the Drogheda North Business Park and was accompanied by an Environmental Impact Assessment Report (EIAR).

**Reason for this Submission**

We are residents living on Kearneys Lane, just north of the proposed development and have a direct line of sight of the Drogheda North Business Park. We object to the proposed development and are concerned that it is not in line with the rural character of the area, nor the planning granted for the site and have in our objection of 22<sup>nd</sup> June 2023 previously raised significant concerns in relation to same. In the following, we outline additional reasons pertinent to the EIAR and the FI as to why the Louth County Council Planning Department should **not grant planning permission** for the proposed development.

**Current Planning Status of the Proposed Development Site**

Drogheda North Business Park was granted planning permission by the Louth County Council Planning Department on the 2<sup>nd</sup> of December 2009, which was subsequently appealed by third parties to An Bord Pleanala. Thereafter, An Bord Pleanala granted Permission for twelve (12 No) **light industrial starter units** on 19<sup>th</sup> October 2010. We would like to highlight that the proposed development by Hibernia Steele is not light industry.

**Scope of Our Objection**

Our objection of the 22<sup>nd</sup> of June 2023 outlined numerous valid and substantiated objections which are on file with Louth County Council. The following are additive to those objections with a specific focus on two issues: **Alternative Site Options** and **Hydrogeological Assessment**.

## 1. Applicant FI Response to the Assessment of Alternatives

The Council's response to the Applicants Assessment of Alternatives, included in the original planning application, was provided in the Planning Report dated 5<sup>th</sup> July 2023:

*The EIA Directive requires the mandatory assessment of alternatives that have identified and studied and to compare their environmental impacts against the proposed location. The consideration of the alternatives set out in chapter 3 of the EIAR is considered too narrow and selective. Accordingly, the applicant is requested submit a comprehensive study of reasonable alternatives which are outside the ownership of the applicant.*

In Section 3 of the EIAR Addendum Document (FI response, December 2023), Boylan Consulting provided an updated Alternatives Assessment. It is our opinion that an insufficient, unvalidated and unacceptable list of alternatives have been provided. It is too narrow and intentionally selective. Our observations/comments are as follows:

- In Section 2.2.2 the Applicant states that *"it is considered that the extent of assessment undertaken in respect of these alternative locations as detailed within this Document should be more than sufficient to comply with relevant Guidance at Section 3.4.1 of the EPA Guidelines on the Information to be Contained in Environmental Impact Assessment Reports."*
  - **To Note:** Section 3.4.3 of the *EPA Guidelines on the Information to be Contained in Environmental Impact Assessment Reports* (May 2022, EPA) states *"Some locations have more inherent environmental sensitivities than others. Depending on the type of project and the range of alternatives that the developer can realistically consider, it may be possible to avoid such sites in favour of sites which have fewer constraints and more capacity to sustainably assimilate the project."*
  - Rather than looking at realistic alternatives in detail the Applicant has identified locations with issues as listed in Table 5 of the FI report, which are unsuitable alternatives. **The FI should have only presented suitable alternative locations in the first instance.** The Applicant fails to provide alternative locations as requested by the Louth County Council Planning Department.

In Section 3.4 the Applicant defines a requirement for a "reasonable proximity" of the alternative sites to within a **20-minute drive** of the Applicants existing premises in Grangegeeth, Co Meath and the M1 motorway. **Why is this criterion being used and what is it based on?**

- Why have alternative locations in Co Meath not been considered? The applicant's current activity is in Meath. The N2 and M3 national roads provide good connectivity across the country as well as access to the M1.
- In Table 6 the Applicant provides responses to some selected objections:
  - Potential locations within the dockland areas to the north of the Boyne or at Platin are dismissed because these are more than 20 minutes (23 minutes!!) from the applicant's current plant location and a statement follows that these locations do not meet the projects objectives? This approach is unreasonable, and we refer to the previous point that only suitable locations should have been considered as alternatives.

- Comments such as –*“it is unknown whether land at the location is currently available and economically feasible to acquire”* – are unreasonable because the purpose of a Further Information request is to give the Applicant sufficient time to undertake a thorough assessment of available options. It is our opinion that the Applicant has dismissed other locations and has intentionally not spent sufficient time nor effort in researching alternative options. The due diligence is dismissive and reads as if the planning has already been granted/secured with Louth County Council for the proposed development and as such the Applicant didn't need to bother addressing alternative locations.
- Comments in relation to locating at Platin Cement Works – *“ It is considered that this zoning designation does not facilitate industrial development of the type / scale proposed. It is considered that the introduction of a new industrial use at this location would unlikely be supported by the Meath County Development Plan and that this location does not offer a good prospect of securing planning permission.”*

**The question arises – was this type of desk study ever undertaken by the Applicant for the proposed location at Drogheda North business Park?** The development is heavy industry, not light and the location in Mell is in a light industrial area. The reference to securing planning permission is questionable, has the applicant and agencies made representation to Louth County Council and been told they'll be supported in their planning application already?

## Conclusion

The FI should have only presented suitable alternative locations in the first instance. The Applicant fails to provide suitable alternative locations or valid substantiated evidence to support their presentations as requested by the Louth County Council Planning Department

## 2. Hydrogeological Assessment

The **hydrogeological assessment** that accompanied the EIAR is **insufficient and has failed to assess the potential impact of the proposed heavy industry development on the underlying aquifer and nearby residential properties.**

In the following we provide our professional understanding of the hydrogeological regime within the site and flag concerning issues with the EIAR.

### Site Geology & Hydrogeological Setting

The hydrogeological assessment that accompanied the EIAR is based on a combination of a desk study and results of an on-site investigation comprising installation of two shallow groundwater wells (BH5 and BH6). These groundwater wells were installed to a depth of seven meters below ground level, within the overburden (clay & gravel) and did not reach the underlying bedrock. The groundwater wells have been screened (i.e. where water can enter the well) between 1 and 7 meters below ground level, through the clays and gravels.

- The site investigation failed to confirm the depth to mudstone / greywacke bedrock beneath the site, **however it does state that the upper portion of the bedrock is weathered and groundwater bearing with further fault and fractures possible within the upper thirty meters of the bedrock. This is concerning.**

- According to the EIAR the bedrock to the south of the site is mapped as being a **regionally important karstified aquifer (Rkd)**. The nearest mapped karst features are 550 m to the southwest, which include a spring, two swallow holes and epikarst. **The EIAR fails to assess the connection between the aquifer located beneath the site with this karstified area located downgradient of the development.**
- **The EIAR statement referencing groundwater vulnerability is incorrect**, it states that *“Based on the borehole logs provided for the two boreholes at the site, neither encountered bedrock, meaning depth to bedrock is at least 6.7 m at the site. This confirms that groundwater vulnerability across the site is Moderate and with deeper lithology data is likely to be Low.”*  
Furthermore *“In general subsoils within the area are deep. The GSI has assigned the application site as having a classification of Low vulnerability.”*  
**Note, the shallow gravels and the fractured bedrock aquifers present beneath the site increases the groundwater vulnerability to high, potentially to extreme.**
- According to the EIAR the geology within the site comprises a thin layer of topsoil underlain by clayey soils ranging to a depth from 3.5m to 4.3m below ground, followed by gravels. The assumption is that **gravels overlay the bedrock**. The depth to bedrock measured at a close by (500 meters to southwest) third party groundwater well was recorded at 16.1 meters below ground. **The EIAR fails to highlight that the presence of the gravels beneath the site will increase the groundwater vulnerability from the reported low to high and potentially to extreme.** In other words – the gravel aquifer is connected to the weathered bedrock located beneath the gravels and together these two formations form an **important groundwater resource** for the numerous nearby residents who attain drinking water from private drinking water wells installed on their properties.
- The **gravel and bedrock aquifers** beneath the site are an important pathway and have significant potential to transport any potential contaminants to nearby receptors. This is a major risk for contamination of the drinking water resources. **The EIAR has failed to highlight this.**

#### Groundwater Sampling & Analysis

- One groundwater quality monitoring event was undertaken at the two shallow groundwater wells located within the site – BH5 and BH6. The EIAR states that the samples were hand delivered on the day of sampling to the laboratory. **According to the chain of custody, which was included in the EIAR, the samples were collected 6<sup>th</sup> April 2021, but only received at the laboratory on the 8<sup>th</sup> of April 2021 two days later. This raises a concern and questions in relation to sample integrity. The EIAR is not correct.**
- The certificate of analysis includes results for samples MW1 and MW2 analysed for typical drinking water parameters. It is unclear to which locations these results refer to.
- The Bedrock aquifer characteristics and quality assessment is based on desktop information only. The proposed activity comprises large scale heavy industry and it is considered prudent to include an on-site assessment of the bedrock type and characteristics of the local aquifer, such as its depth, permeability, and recharge rate. **The assessment as presented in the EIAR is unacceptable and complacent in the absence of such important information.**

- The EIAR fails to assess the impact of potential contaminants to the groundwater quality, e.g. no detailed assessment of potential impacts of chemicals stored and used during heavy industry processing at the proposed site was undertaken.

Local residents' groundwater quality has not been considered. The applicant states that a "third party well survey was not carried out." There are several private residents near the proposed development which are dependent on groundwater as their drinking water source. These residents have legitimate concerns in relation to groundwater contamination.

#### Proposed Final Ground Levels of the Development

- As referenced in the EIAR, the depth to groundwater at the onsite wells was measured on two occasions with the water level observed to range between **1.16 m and 1.58 m below ground level**, i.e., between **40.26 maOD and 47.37 maOD** (meters above Ordnance Datum).
- According to the *Drawing Main Building / Welfare Cross Sections (No C216-DR-BCON-CE-008) dated 3<sup>rd</sup> March 2023*, the final floor level (FFL) of the main building on the proposed site will be **43.0 maOD**. The proposed FFL of the onsite buildings are below the recently measured groundwater levels at the site, which ranged between **40.26 maOD and 47.37 maOD**.
- Drawing *Drainage Layout (No C218-DR-BCON-CE-101) dated 23<sup>rd</sup> March 2023*, shows that the proposed full retention interceptors are installed below ground, i.e. below the 43 maOD levels and the top water levels within the onsite attenuation tank have been shown at a level of 40.06 maOD.
- The onsite groundwater levels are above the proposed FFL (finished floor levels) of the proposed development. **The EIAR fails to address this.**

**The EIAR does not address impacts caused by planned construction activities below the groundwater table, nor does it address impacts of the operation of the proposed plant without adequate groundwater protection measures being considered.**

#### Potential Impacts to the Environment

The proposed development is situated close to **open water reservoirs (Rosehall and Killineer)** considered by Irish Water as part of **drinking water sources for Drogheda**. The closest surface water stream is located 380 meters to north and west and flows to the River Boyne, which is a designated Salmonid Water under the EU Freshwater Fish Directive and is classified as a Natura 2000 site. The River Boyne is located south of the Site. The proposed volume of chemicals to be stored and utilised at the site for the heavy industry processing activity has the potential to have a detrimental impact on the wider environment through migration via surface water and groundwater, and air pollution. As can be seen in the following photo – Rosehall Reservoir is located 130 m to east, Killineer Reservoir 390 m to north, the groundwater filled quarry lakes are located 630 m and 900 m to south and the Tullyeskar Stream flows 380 m north and west towards the River Boyne.



Louth County Council's Planning Report which is based on its site visit of 15<sup>th</sup> June 2023 makes the following conclusion in relation to the hydrogeological assessment supplied with the EIAR which accompanied the original Planning Application dated 22<sup>nd</sup> May 2023:

***I am satisfied that the submitted EIAR has documented that the proposed development will not have any undue negative impact on the residential amenities of dwellings in the immediate vicinity and that the mitigation measures proposed will ensure that residents, wildlife, and farm animals will not be negatively affected.***

*An assessment of impacts to the surrounding hydrological and hydrogeological environment that have potential to occur due to the proposed development works was undertaken. A number of temporary mitigation measures will be implemented to protect surface water quality during the construction phase. Stormwater generated on concrete in the southern part of the site shall pass through a hydrocarbon interceptor with silt trap and an attenuation device before entering receiving surface waters. Hence there is no potential for contaminated runoff to leave the site and enter the Mell Stream or River Boyne. All mitigation measures proposed are set out in the EIAR and as such I am satisfied that there will be no significant adverse impacts as a result of the proposal on the receiving groundwater and surface water environment.*

**We question how Louth County Council has come to the above conclusion and the level of due diligence undertaken in respect to the EIAR?**

We trust that the Louth County Council Planning Department will carefully review and address the concerns we have raised, promoting sustainable and responsible planning/development practices that prioritise the well-being of the community and the preservation of our shared environment. The proposed development is detrimental to this rural region, is not light industry, impacts the quality of life and poses a risk to the 60 families who have objected to this planning application. Road infrastructure at an already congested Rosehall roundabout has not been considered nor the cumulative impacts of the thousands of houses under construction close by for road access and water resources.

Based on our observations we object to this development and its unsubstantiated EIAR and FI.

Kind regards,

*Niamh Vainio-Mattila*

Niamh Vainio-Mattila

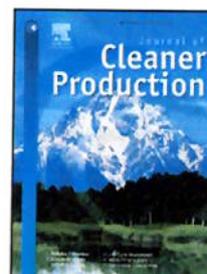
*Thomas Vainio-Mattila*

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# Accepted Manuscript

A holistic framework for assessing hot-dip galvanizing process sustainability

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# A holistic framework for assessing hot-dip galvanizing process sustainability

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## Abstract

Hot-dip galvanizing is considered one of the most important corrosion protection alternatives for steel; however, its poor environmental performance has been a matter of concern. Even though many researchers have dealt with this topic in the past none of them have jointly dealt with the triple bottom line of sustainable development, and with the random and epistemic uncertainty of its measurement. For that reason, in this work, the sustainability of the hot-dip galvanizing process is investigated integrating: (a) 17 indicators taken from the 4 categories of the GREENSCOPE methodology and one quality performance indicator which is directly related to ISO 1461. (b) The additive utility method for multi-criteria decision-making. (c) The fuzzy analytic hierarchy process used to calculate the relative weights of both indicators and categories by means of a survey. (d) The hierarchical partitioning analysis used for determining the process stages that have a higher impact on sustainability variation, and others useful and suitable statistical tools for data analysis. Furthermore, the proposed framework is tested for a particular hot-dip galvanizing process, considering a random generation of each batch size, steel item characteristics and operating conditions via the kinetic Monte Carlo method. The results show that the stages of pickling and fluxing are critical for the analyzed system and they are not expected to be improved without a significant modification of the process. The proposal outlined in this paper might help designers, process engineers and researchers for a better decision-making process, focusing on the most critical stages while considering the trade-off between the three dimensions of sustainable development.

## Keywords

Hot-dip galvanizing, sustainability, GREENSCOPE, additive utility methods, fuzzy analytic hierarchy process, hierarchical partitioning analysis

## 1. Introduction

Steel is the most frequently used structural metal in the world, and given that it is highly vulnerable to corrosion, it needs to be protected. One of the most common methods for steel protection is the hot-dip galvanizing (HDG) process. HDG consists of the coating of steel by dipping it in a molten-zinc bath at 450°C to produce a Zn-Fe alloy. Many wastes and by-products are produced as a result of the production line activities of HDG, some of

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which are fats; oils; spent baths solutions from the degreasing, pickling and fluxing stages; ash, dross and splash of zinc; and vapors and gases released to the atmosphere.

At the core of sustainable development (SD) is the need for taking into account the overlapping of environmental, social and economic dimensions, which are well-known as the triple bottom line of SD. For the above reason, many governments have begun their action plans and strategies for SD, mainly focused on SD inside industry (Azapagic & Perdan, 2000). In this way, the HDG industry, as a system that interacts with its surroundings by means of environmental, social and economic aspects, has been no exception. Therefore, numerous studies have dealt with understanding this particular process, from different spatial-temporal perspectives and taking into account at least one of the bottom lines of SD.

For example, from the point of view of environmental sustainability, Alzate, Oquendo, and Muñoz (2004) depict the polluting and hazardous materials that are produced as a result of HDG. Kong and White (2010) propose cleaner production as a possible path for reducing the negative environmental impacts of HDG and accomplishing SD goals. Likewise, Fresner et al (2007) focus on the reduction of environmental aspects, but in this case, for using the zero emissions concept, this study shows that environmental solutions may be technically feasible, but not necessarily economically viable at the same time. The latter also demonstrates that there is a possible trade-off between economic and environmental aspects. Therefore, both objectives may not be simultaneously satisfied.

Like the above studies, it is possible finding in the literature other studies dealing only with the relationship between environment and HDG. For instance, Karkoszka (2017) uses a matrix of environmental risks for assessing HDG, while Benedetti, Baldo, Carlo, and Maglioni (2003) apply life cycle assessment of HDG for defining its environmental sustainability level. Tongpool, Jirajariyavech, Yuvaniyama, and Mungcharoen (2010) also use life cycle assessment on the whole supply chain of steel identifying the environmental impacts of HDG process. On the other hand, there are other researchers focused on environmental sustainability, but with a special attention to end-of-pipe technologies such as Lobato, Villegas, and Mansur (2015) and Regel-Rosocka, Cieszyńska, and Wićniewski (2007). The former study deals with solid wastes management, while the latter addresses the regeneration of spent pickling solutions.

Hegyi, Păstrav, and Rus (2015) go forward with their study taking into account both economic and environmental dimensions to assess the sustainability of hot-dip galvanized rods. Similarly, other researches focus on assessing sustainability of hot-dip galvanized products with the same two bottom lines, such as the American Galvanizers Association (2008) who considered HDG in the construction of alternative energies facilities, and Tiuc and Rus (2016) with HDG steel for infrastructure.

Meanwhile, researchers like Akamphon, Sukkasi, and Boonyongmaneerat (2012) use a cost analysis to evaluate the efficacy of a new technology for reducing zinc usage at HDG, this study expresses the importance of integrating the economic dimension. However, it is important to highlight that assessing a product or process only considering the economic dimension does not determine in *stricto sensu* its capability to achieve a state of global sustainability, in other words, a balance between environmental, social and economic pillars.

Additionally, it is important to mention the studies which consider the triple bottom line of SD, remarking that available assessments in the literature only take into account the final product and not the process. On one hand, the American Galvanizers Association

(2015) examines the economic dimension and relegates the environmental and social ones only to qualitative assessments. On the other hand, Melorose, Perroy, and Careas (2015) also raise a cradle-to-grave evaluation with a special focus on the economic and environmental bottom lines and a description of the benefits in safety for using galvanized structural steel.

Other interesting aspect is that sustainability as a quantitative variable is subject to measurement, thus it can be analyzed from metrology perspective as a measure with associated uncertainty (Brandi & Dos Santos, 2016). Therefore, random uncertainty due to natural stochasticity of the system under study and epistemic uncertainty because of insufficient knowledge or insight about something examined, they both should be handled (Dutta, 2013). For instance, Piluso, Huang, Liu, and Huang (2010) state that the effectiveness of the industrial sustainability assessment depend on the ability to find the complex interrelationships among the parts of the system of study and the quality of information and possessed knowledge. On the other hand, Ciuffo, Miola, Punzo, and Sala (2012) identify, that the definition of boundaries (physical, economic and social), the intrinsic subjectivity of assessment tools and the incapacity to mimic our world, are sources of uncertainty of sustainability evaluation.

For all that, the purpose of this study is to develop a holistic approach that takes into account the triple bottom line of SD to determine the capability of any HDG process for accomplishing a satisfactory level of sustainability. At the same time, focusing on unit operations and their performance, the desirable framework should have a spatial-temporal approach on the production process so that improvements can be made directly at the most critical stages. This would allow researchers, process and design engineers, as well as any other stakeholder, to identify the real sustainability issues caused by poor performance of the manufacturing process. Furthermore, another goal of this paper is to provide an additional tool for including uncertainty in the holistic framework.

Therefore, for accomplishing the above goals, in the section 2 of this paper a holistic framework will be presented: (a) 17 process-oriented sustainability indicators from GREENSCOPE which were used to track the sustainable performance both global process and each unit operation (Ruiz-Mercado et al., 2012). (b) A HDG technical metrics from ISO 1461 that was implemented to know how well the global process meets the quality requirement of zinc coating thickness according to the gauge of steel parts. (c) Additive utility method for multi-objective decision-making employed to calculate the process capability to achieve sustainability (Salvatore, 2008). (d) Fuzzy inference which was used to obtain stakeholders' worries, fears and thoughts by means a survey (Sabaghi, Mascle, Baptiste, & Rostamzadeh, 2016). (e) Different statistical tools such as hierarchical partitioning analysis were implemented, the latter one for identifying what unit operations have the highest effect in sustainability variability (Chevan & Sutherland, 1991). Additionally, as the holistic framework proposed can be used with data obtained from either the real process or a simulation, in section 3 a kinetic Monte Carlo method will be proposed to mimic a specific HDG process taking into account randomness associated to the process, steel pieces and surroundings. Finally, in section 4 the assessment of the above case of study under the holist framework will be showed, where pickling and fluxing steps constitute the critical points, and this only has a probability of 45.26% of being sustainable without any process configuration change.

## 2. Methodology

The following lists have symbols, subscripts and superscripts which are used in this section.

### Subscripts

$i$ :	It represents a predictor when talking about hierarchical partitioning analysis or about indicator in other cases	$\alpha$ :	It represents a sustainability category
$j$ :	It represents a unit process or a process step	$P$ :	It represents the global process, in this case HDG
$s$ :	It represents an item of the sample	$\beta$ :	It represents the indicator for comparison with marginal rate of substitution
$Q$	Indicator of quality zinc coating thickness		

### Superscripts

$j$ :	It represents a unit process or a process step	$\alpha$ :	It represents a sustainability category
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### Symbols

$(\%)G_i$ :	GREENSCOPE score of indicator $i$	$x_i$ :	Value of indicator $i$
$x_{best,i}$ :	Best scenario of indicator $i$	$x_{worst,i}$ :	Worst scenario of indicator $i$
$k_i$ :	Relative weight of indicator $i$	$U_{Tot}$ :	Total additive utility
$U_i$ :	Utility of indicator $i$	$m$ :	Number of process steps
$MRS_{i\beta}$ :	Marginal rate of substitution of $\beta$ with respect to $i$	$U_{p,s}$ :	Process utility for item $s$ in the sample
$x_{best,Q}$ :	Best scenario of quality indicator	$x_{worst,Q}$ :	Worst scenario of quality indicator
$U_{Q,s}$ :	Utility of quality indicator at item $s$ of the sample	$MRS_{iQ}^{(\alpha j)}$ :	Marginal rate of substitution of quality for indicator $i$ at category $\alpha$ and process step $j$
$\lambda_Q$ :	Relative weight of quality category	$U_{ajs}$ :	Utility of category $\alpha$ at process step $j$ and item $s$ of the sample
$(\%)G_{i\alpha j s}$ :	GREENSCOPE score of indicator $i$ of category $\alpha$ at process step $j$ and item $s$ of the sample	$r^{*2}$ :	Critical value for Mac Nally (1996) hypothesis testing
$t_{1-\frac{\nu}{2}, N-1}$ :	Value of t-distribution with significance level of $\nu$ and $N-1$ freedom degrees	$U_p$ :	Utility of the process or capacity to satisfy a sustainability state

$LM_p$ :	The minimum admissible value of the process capacity to achieve a sustainable state	$LM_{iaj}$ :	The minimum admissible value for each indicator $i$ , which belongs to sustainability category $\alpha$ , at specific unit process $j$
$\mu_p$ :	Population mean of process utility	$\sigma_p$ :	Population standard deviation of process utility
$\bar{U}_p$ :	Sample mean of process utility	$Z_{\frac{\alpha}{2}}$ :	Value of standard normal distribution with significance level of $\alpha$

The toolkit used to build the holistic framework for assessing sustainability, not only of a HDG process but also of a wide variety of manufacturing processes, was the result of a comprehensive literature review.

According to the Plan-Do-Check-Act (PDCA) cycle, a continuous process improvement approach based on iterative steps for managing processes, “if you cannot measure it, you cannot manage it”. For that reason, it is mandatory to have a group of sustainability metrics that help quantify the sustainability level of the HDG process. Additionally, Azapagic and Perdan (2000) established that sustainability assessment can be classified depending on the desired type of analysis in: process-, product- and company-oriented. Moreover, Martins, Mata, Costa, and Sikdar (2007) suggest that metrics can be grouped based on the number of dimensions of SD: (a) one-dimension (1D) metrics which cover an economic, environmental or social focus. (b) Two dimensions (2D) metrics which cover the intersection between two out of three of SD bottom lines, socio-economic, eco-efficiency and socio-ecology focus. (c) Three dimensions (3D) metrics that are called metrics of SD. Finally, other important aspect in the sustainability analysis is the different spatial scales. If both upstream and downstream of the process are not included, the analysis will be done at the process level (gate-to-gate analysis). If aspects about raw materials, product use and disposal are incorporated, the study will be a common life cycle assessment. Moreover, if details about natural resource and ecological goods and services are dealt, the research will be an ecological life cycle assessment (Smith, Ruiz-Mercado, & Gonzalez, 2014a).

A second aspect that is important to consider in the sustainability analysis is that there are three main dimensions which must be studied simultaneously. As it was shown before, there is a trade-off between the three bottom-line dimensions as all of them may not necessarily be satisfied at the same time. Additionally, a lot of metrics must be added to the analysis since it is very difficult to have only one indicator representing all important characteristics of SD. Therefore, it is important to use a multi-objective decision-making method that can be easily implemented in industry for making fast decisions. Similarly, the third aspect that should be taken into consideration is that nearly all decision-making processes have more than one stakeholder, thus the holistic framework must include a special tool that allows collecting the decision-makers’ thoughts, fears and worries about the process.

Finally, the fourth and the most important aspect of this work is the tool for finding the critical points of the process. The critical points are those unit processes and their transfer phenomena and/or reaction paths that affect in a higher degree the sustainability of the process. Since they are related with the variability of process sustainability, a suitable

statistical tool must be used for determining the critical points which can take into account both epistemic and random uncertainties in sustainability measurement.

Figure 1 is an overview of the proposed framework for assessing HDG sustainability. As it can be seen, there are two branches before additive utility method (AUM). In the lower branch, the workflow is as follows: first, process life cycle inventory is obtained from real or simulated process. After that, sustainability indicators and categories are computed by means of GREENSCOPE. On the other hand, the upper branch is as follows: first, stakeholders' opinions are obtained through a survey. Next, these linguistic expressions are expressed as relative weights for both indicators and categories by fuzzy analytic hierarchy process (FAHP). Therefore, after computing measurements and weights for each indicator, AUM is used to estimate the utility of unit processes. At the final stage of methodology, the different statistical tools, such as hierarchical partitioning analysis (HPA), are employed to obtain the critical points and other useful information for the decision-makers. All the above tools will be explained better in the following sections.

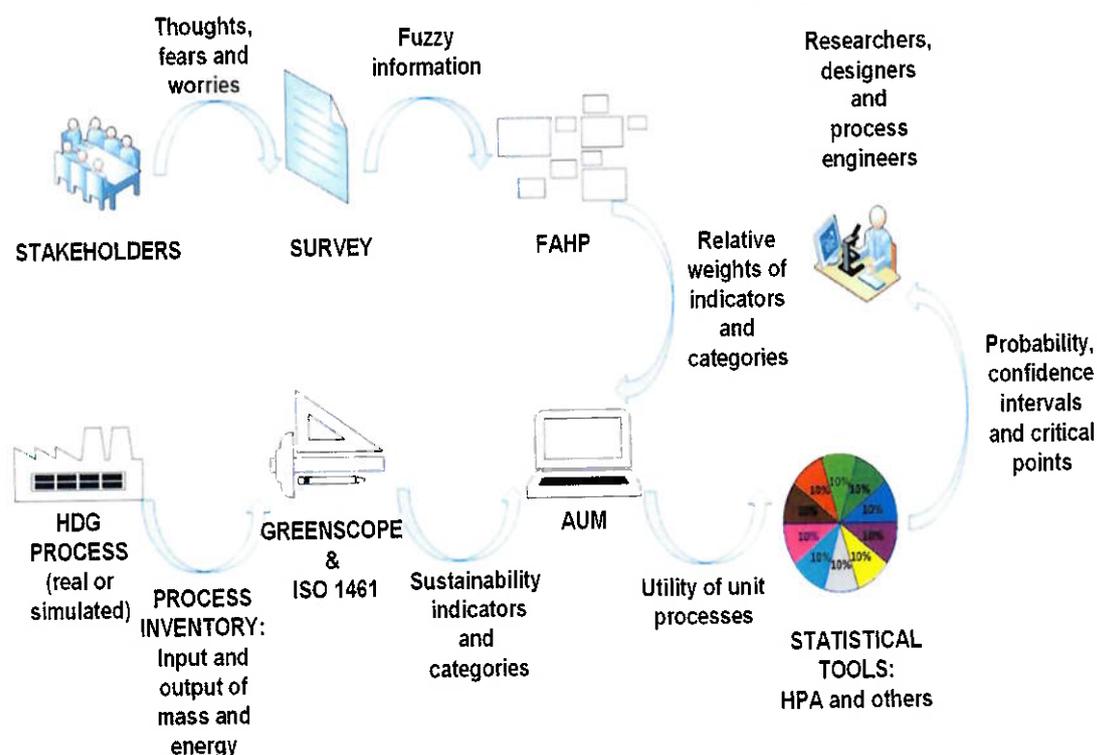


Figure 1. Step-by-step and underlying idea of the proposed methodology (adapted from Hernández-Betancur (2018)).

### 2.1. Metrics and categories

As mentioned in the previous section, a set of metrics is needed to measure the sustainability of the HDG process. So, the set of metrics was based on the metrics proposed by GREENSCOPE<sup>2</sup> (Gauging Reaction Effectiveness for the Environmental Sustainability

<sup>2</sup> GREENSCOPE: <http://ow.ly/2RBo30fVnzq>

of Chemistries with a Multi-Objective Process Evaluator) keeping in mind that the target is to make a process-oriented analysis without the downstream and upstream life cycle, while taking into account the triple bottom line of SD. GREENSCOPE is a method created by the U.S. Environmental Protection Agency for answering two questions: Is an alternative green, and is it sustainable? (Smith & Gonzalez, 2004).

GREENSCOPE is based on a set of 139 quantitative sustainability indicators for a gate-to-gate assessment of chemical processes. The indicators in the method are grouped in four categories: (a) environmental indicators, which take into account the principles of green chemistry and engineering to prevent pollution. (b) Efficiency indicators related to materials use in processes or unit operations and also consider the underlying chemistry of a chemical reaction or a specific task (such as a separation). (c) Energy indicators which quantifies the intake of energetic resource in a process. (d) Economy indicators, which are of great importance since the process can exist only if it is profitable.

According to Ruiz-Mercado et al. (2012), the reason for not grouping them in the economic, environmental and social categories is because these are effective for a company-oriented analysis, but not for process-oriented decision making. For instance, in the traditional approaches for assessing sustainability, it is common to find that indicators of energy and materials are in the environmental category, but they must be observed independently to identify what steps of the process, process specifications and/or operating conditions need to be improved (Ruiz-Mercado et al., 2012). Furthermore, GREENSCOPE uses quantitative indicators of safety and health in the environmental category, but not other indicators about intangibles cost such as the business perception of the society and its image because they are really critical at the company level (Ruiz-Mercado et al., 2012).

Additionally, other important aspect is the normalization procedure. GREENSCOPE grades the indicators using a sustainability scale for each indicator  $i$ , taking into account the worst and the best (or target) scenario (see equation 1).

$$(\%)G_i = \frac{|x_i - x_{worst,i}|}{|x_{best,i} - x_{worst,i}|} 100\% \quad (1)$$

The normalization procedure shown in equation 1 allows decision makers using the adequate reference states for each indicator  $i$  ( $x_{worst,i}$  and  $x_{best,i}$ ). So, they can consider aspects such as the current legislation and/or the company's target in the decision-making analysis and they can also tune the whole framework with their concerns and external process aspects.

Looking for an easier analysis during decision making, only a fraction of all GREENSCOPE metrics were considered for assessing the sustainability of the HDG process. Thus, only 4 out of 26 efficiency metrics, 11 out of the 66-environmental metrics, 1 out of 33 economic metrics and 1 out of 14 energy metrics were selected from GREENSCOPE. Additionally, the ISO 1461, which establishes the rules about zinc coating thickness, was used to create a new indicator focused on HDG quality.

The environmental metrics were chosen in accordance to Colombian Law (Article 6 of Resolution 909 of June 5<sup>th</sup> of 2008 from the Colombian Department of Environment, Housing and Territorial Development, where the atmospheric pollutants to be tracked in electroplating processes are defined. Article 8 of Resolution 0631 of March 17<sup>th</sup> of 2015 from the Colombian Department of Environment and Sustainable Development, where the

parameters and admissible maximum limits in a punctual dumping to water bodies and sewages are defined. Decree 4741 of December 30<sup>th</sup> of 2005 about hazardous residues and wastes). Research done by Melorose, Perroy, and Careas (2015) about cradle-to-grave life cycle assessment of hot-dip galvanized steel and by Kong and White (2010) who studied the environmental aspects of HDG were also considered. Table 2 presents the selected environmental metrics.

## 2.2. Additive utility method

The trade-off in the multi-objective decision process will be dealt with the additive utility method (AUM). According to Smith and Ruiz-Mercado (2014), the AUM is one of the most common method for decision making. Additionally, utility is a term related to worth (or the ability for satisfying something). So, each objective or desire has its own utility or its own utility rating ( $U$ ).

$$U_{Tot}(x_1, \dots, x_m) = \sum_{i=1}^m k_i U_i(x_i) \quad (2)$$

As equation 2 shows, AUM is only a weighted average of all individual utilities. The weights of each indicator are only positive values and their sum is equal to 1. Smith, Ruiz-Mercado, and Gonzalez (2014b) provide an easy way to calculate the utility function for each indicator (Equation 3):

$$U_i(x_i) = \frac{|x_i - x_{worst,i}|}{|x_{best,i} - x_{worst,i}|} \quad (3)$$

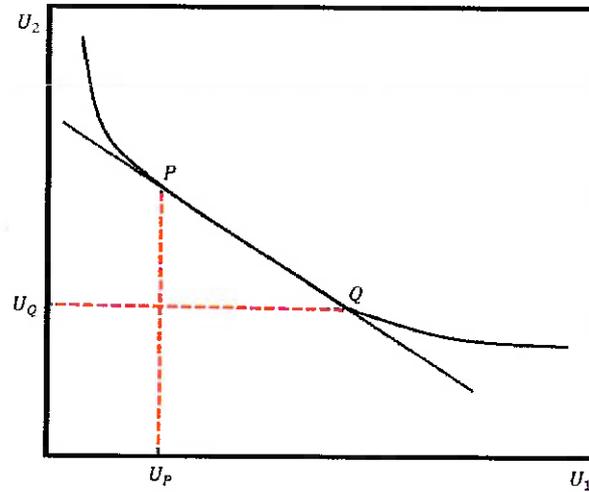


Figure 2. Indifference curve (adapted from Smith & Ruiz-Mercado (2014))<sup>3</sup>.

Figure 2 presents the indifference curve. The indifference curve is the representation of several combinations between two objectives which produce the same total utility (Salvatore, 2008). Among the characteristics of this curve are: the slope is negative which makes sense as a result of the trade-off between criterions; the curve is convex, and it does not intercept with other ones because the same combination of objectives cannot produce different utilities (Salvatore, 2008). On the other hand, the slope of the curve is known as marginal rate of substitution (MRS).

According to Salvatore (2008), the MRS is the amount of one good that someone is willing to give up for an additional amount of another one, but maintaining the same satisfaction level or being on the same indifference curve. Precisely, the indifference curve is convex because the MRS trajectory is downward ( $MRS_{12} = -dU_2/dU_1$ ).

Smith, Ruiz-Mercado, and Gonzalez (2014b) propose equation 4 for calculating the MRS when the AUM and proportional punctuations are used:

$$MRS_{i\beta} = \frac{k_i/|x_{best,i} - x_{worst,i}|}{k_\beta/|x_{best,\beta} - x_{worst,\beta}|} \quad (4)$$

Using equations 1, 2, 3 and 4, after a mathematical manipulation with a special focus on the hierarchical structure of indicators, the HDG process features and the need to measure random and epistemic uncertainty, equations 5 and 6 were deduced for including the GREENSCOPE indicators.

<sup>3</sup> The straight line in the curve is a particular case of indifference curve well-known as perfect substitution where the MRS is constant. "this means that an individual is always willing to give up the same amount of good  $U_2$  for each additional unit of good  $U_1$ " (Salvatore, 2008).

$$U_{P,s} = \sum_{j=1}^m \left( \sum_{\alpha=1}^4 U_{\alpha js} \right) + |x_{best,Q} - x_{worst,Q}| U_{Q,s} 100 \quad (5)$$

$$U_{\alpha js} = \sum_{i=1}^{17} (\%) G_{i\alpha js} |x_{best,i}^{(\alpha j)} - x_{worst,i}^{(\alpha j)}| MRS_{iQ}^{(\alpha j)} \quad (6)$$

It is important to clarify that all MRSs would be calculated with respect to a quality indicator and the subscript  $s$  represents an item of the sample which can be obtained either *in vivo* (data retrieved directly from the real process) or *in silico* (via computer simulation). Additionally, the subscript  $s$  is written below those variables which are dependent of each sample.

### 2.3. Fuzzy analytic hierarchy process

An important point in this discussion, it is to find a method for calculating the relative weight of each category and indicator. In this work the fuzzy analytic hierarchy process (FAHP) will be used for estimating the relative important or weight of each metric and sustainability category, because FAHP is able to handle inconsistencies between experts' opinions (Sabaghi et al., 2016). For more information about fuzzy operations employed in this paper, the reader is encouraged to check Sabaghi et al. (2016). Furthermore, additional information and examples about the use of FAHP can be found in Rouyendegh and Erkan (2012), Srichetta and Thurachon (2012), and Chang (1996).

An important aspect to use FAHP is the fuzzy numbers set. In this work, triangular fuzzy numbers (TFNs) are used because of their easy handling. Thus, TFNs implemented here are the proposed by Srichetta and Thurachon (2012), which have been broadly used in literature. On the other hand, thoughts, fears and worries of the different stakeholders are collected by means of surveys with pairwise comparison matrixes<sup>4</sup>.

### 2.4. Statistical tools for the analysis

#### 2.4.1. Procedure to incorporate uncertainty

As it was said before, sustainability should not be reported as a deterministic value, but as a stochastic variable with a confidence interval at a confidence level selected by stakeholders. Moreover, it is possible to associate a probability that the process will be sustainable under established parameters by stakeholders and/or policies.

The normal distribution function is an analytical tool which is commonly used as a simple model for complex events. Additionally, the normal distribution is useful when the variability is caused as a result of many effects, where no one is predominant (Ahi & Searcy, 2013). Therefore, the assumption is that  $U_p$  will be normally distributed ( $U_p \sim N(\mu_p, \sigma_p^2)$ ).

So, if each process step  $j$  has its own measurement for the indicator  $i$  which belongs to sustainability category  $\alpha$ , it would be possible that decision-makers establishing a minimum admissible value for each indicator at specific unit process, which will be called

<sup>4</sup> Survey (Spanish): <http://ow.ly/zU9S30fVncA>.

$LM_{iaj}$ . It is important to clarify that  $LM_{iaj}$  is different from both the best and worst scenarios of the GREENSCOPE score, and even it is a point between  $x_{worst,i}$  and  $x_{best,i}$ . Therefore, if all  $LM_{iaj}$  are used in the equation 5,  $LM_p$ , the minimum admissible value of the process capacity to achieve a sustainable state, would be obtained. Then this value could be employed for calculating the probability that the process will be sustainable (equation 7)

$$P_{sustainable} = \frac{|x_{best,Q} - x_{worst,Q}|}{\lambda_Q} 100 \int_{LM_p} \frac{1}{\sigma_P \sqrt{2\pi}} \exp\left(-\frac{(U_p - \mu_P)^2}{2\sigma_P^2}\right) dU_p \quad (7)$$

To understand the upper limit of the above integral, the reader can use equation 5 and remember that according to equation 3,  $U_{Q,s}$  and every  $U_{aj,s}$  can have 1 as maximum value. Furthermore, observing the second term of equation 5, so that this could be obtained, the equation 3 had to be multiplied by  $|x_{best,Q} - x_{worst,Q}|100/\lambda_Q$ . Thus, the former term is the maximum possible value of  $U_p$  (talking of population) or  $U_{p,s}$  (talking of sample).

Moreover, by the above, the fact that  $U_p$  is supposed to be normally distributed and as normal distribution function is symmetric, the “equivalent” normal function for population of  $U_p$  would approximately have a standard deviation as equation 8.

$$\sigma_P \approx \frac{\frac{|x_{best,Q} - x_{worst,Q}|}{\lambda_Q} 100 - \mu_P}{3} \quad (8)$$

Finally, using a sample of size  $N$ , the sample mean ( $\bar{U}_p$ ) can be calculated for a specific process. So, the confidence interval of  $\mu_P$  with significance level  $\nu$  can be calculated (see equation 9, where  $Z$  is standard normal distribution).

$$IC_{\mu_P} = \left[ \bar{U}_p - Z_{\nu} \frac{\sigma_P}{\sqrt{N}}, \bar{U}_p + Z_{\nu} \frac{\sigma_P}{\sqrt{N}} \right] \quad (9)$$

#### 2.4.2. Hierarchical partitioning analysis

Finding the critical points of the process is a crucial issue to allow decision makers to take good decisions for process improvement. Hierarchical partitioning analysis (HPA) is a good tool for identifying those critical spots. For instance, Mac Nally (2016) uses HPA for selecting the “optimal” regression model in conservation biology, biogeography and ecology based on the impacts of independent variables upon a dependent variable. Thus, HPA is both efficient and effective, the first one from the point of view of time used and the second one from the target achievement.

As it was said before, AUM would be the multi-objective decision making procedure used in this paper. In the AUM model, the process utility is a linear function of each stage utility which is also a linear function of the sustainability indicators related to the performance of transport phenomena and reactions taking place at each stage.

HPA uses the coefficient of determination of a multiple regression ( $R^2$ ) which measures the proportion of variance of a dependent variable that is explained by independent variables. Other important aspect of HPA is that it quantifies the degree of correlation between a predictor or independent variable and a response or dependent variable. So, HPA is useful to identify the most probable causal factors.

The whole HPA procedure used in this work was developed by Chevan & Sutherland (1991). Since  $R^2$  is the sum of both the individual ( $I_i$ ) and joint ( $J_i$ ) contributions of each predictor  $i$ , in HPA, many multi-linear regressions are done by considering different combinations of predictors. The number of predictors chosen for each multi-linear regression depends on the corresponding hierarchical level, beginning with only one predictor and ending with all predictors selected. Next, several hierarchical subtractions are done for finding the individual effect of each predictor. A zero-order correlation ( $R_i$ ) is when the linear regression is done only with one predictor, thus, " $I_i$  represents the part of  $R_i$  that remains after some part ( $J_i$ ) of the relationship of variable  $i$  have been absorbed by  $i$ 's covariance with the other independent variables in the regression" (Chevan & Sutherland, 1991). This can be seen in equation 10.

$$\sum_{i=1}^m R_i = \sum_{i=1}^m I_i + \sum_{i=1}^m J_i \quad (10)$$

According to equation 10, if the variables are not correlated, the second term on the right is 0, i.e., there is no joint effect. On other hand, the sign of that term determines the nature of the contribution since the predictors can act both in an additive ( $J_i > 0$ ) or suppressive ( $J_i < 0$ ) way.

For concluding, the most important variables have the highest independent contribution. So, the critical points of the process are those predictors which contribute with the highest value of  $I_i$  in the linear model of  $U_p$  and its critical physical phenomena whose  $I_i$  contributes in the highest degree to each stage utility.

$$r^{*2} = \frac{t^2}{N-2 + t^2} \frac{1 - \frac{v}{2}N-1}{1 - \frac{v}{2}N-1} \quad (11)$$

The independent effects which are obtained by the procedure described before can be evaluated in accordance with Pareto's principle also known as 80/20 rule, which establishes that a great part of the effect (80%) is the result of few key causes (20%). Furthermore, the results, which would be obtained through Pareto's principle, can be contrasted synergistically with a hypothesis testing presented by Mac Nally (1996) where the critical value based on t-distribution ( $r^{*2}$ ), with sample size  $N$  ( $N - 1$  freedom degrees) and significance level  $v$ , is calculated as it is showed in equation 11. Although Mac Nally test is used here, this needs normalizing both dependent and independent contributions with respect to the highest independent value.

### 3. Case of study

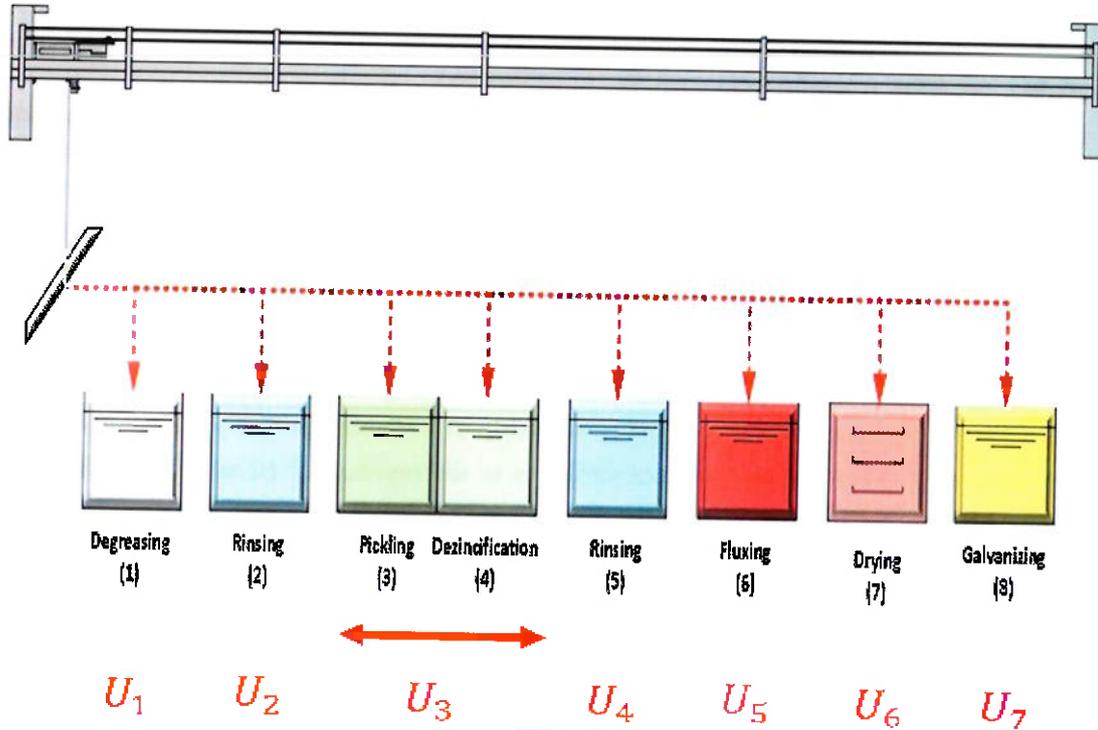


Figure 3. Configuration of HDG process simulated (developed by Hernández-Betancur (2018)). Here,  $U_1$ ,  $U_2$ ,  $U_3$ ,  $U_4$ ,  $U_5$ ,  $U_6$  and  $U_7$  are the utilities for degreasing, rinsing 1, pickling (normal and dezincification), rinsing 2, fluxing, drying and galvanizing, respectively.

Kinetic Monte Carlo method was used to mimic a specific HDG process whose configuration is presented in Figure 3. The basic process stages include: Degreasing, rinsing, pickling, dezincification, fluxing, drying and galvanizing. Furthermore, the mathematical model used considered the following random variables:

1. For each steel item: gauge, mass, chemical composition, grease and oil content, rust amount, lot size, probability of appearance.
2. HDG process: operating conditions of each unit process such as volume, temperature and initial composition as well as reprocessing probability of steel items.
3. Surroundings: room temperature, which was supposed to be normally distributed with mean  $22^{\circ}\text{C}$  and standard deviation  $2^{\circ}\text{C}$  for Medellín, Colombia.

Steel pieces were simulated like squared sheets with constant density and heat capacity  $7850\text{kg/m}^3$  and  $460\text{J/kgK}$ , respectively. The steel gauge could vary from  $0.0003$  to  $0.032\text{m}$  according to commercial steel sheets sold by the Colombian companies ACESCO and METAZA. Furthermore, for representing the steel items, 10 of the most representative ones from a Colombian galvanizer company production were used, whose information is in Table 1. Therefore, with the information in Table 1 the probability of appearance, mass and lot size were supposed to be uniformly distributed. On the other

hand, as rust layer mass can be from 300 to 590  $g/m^2$  and silicon amount which is ideal for galvanizing is between 0.15 and 0.25%wt, they were expected to be uniform random variables as well. Additionally, 30% of steel pieces that came into the process facility needed to be degreased and the rate between oil and grease amount per steel mass was 10g/ton (Hernández-Betancur, 2018).

Table 1. Mass, probability and lot size associated to steel items (Hernández-Betancur, 2018).

Item	Probability	Unit mass (kg)	Uncertainty (kg)	Lot size
1	0.2909	0.02554	0.00001	200 – 54000
2	0.1076	0.09655	0.00004	576 – 29843
3	0.0950	0.009433	0.000005	1092 – 23101
4	0.0941	0.08463	0.00003	285 – 23661
5	0.0930	0.02441	0.00001	46 – 37230
6	0.0743	0.12288	0.00005	10000 – 24000
7	0.0671	0.07010	0.00003	428 – 28636
8	0.0642	0.05805	0.00003	4614 – 42930
9	0.0596	0.08859	0.00004	3300 – 39600
10	0.0542	0.010617	0.000006	111600

In respect of representation of each process stage, energy and mass balances were employed to represent them taking into account operating conditions of these ones and the characteristics of key phenomena inside them. For instance, for mimicking degreasing step was supposed that the alkali solution ( $NaOH$ ) changed once a year, the concentration of initial bath and the uncertainty for it were 15 %wt  $NaOH$  and 1%wt (which is normal for an industrial concentration meter), respectively. Also, since the common temperature in a degreasing process is 50°C, that was employed as well as it was supposed to be distributed uniformly from 48.9 to 51.1°C due to thermocouple type J tolerance. The solution entrainment per steel mass was 1L/ton and the efficiency of bath 70%. Furthermore, greases and oils were represented as triglycerides because they are the most common ones. The molecular weight of  $C_3H_5$  portion was 41.0716 and the sum of acidic radicals, which was supposed to be uniform variable, was between 94 and 96% of total molecular weight both of the greases and oils (Hernández-Betancur, 2018).

Finally, it useful to clarify that with the steel pieces in Table 1 and by taking the fact that 180ton per month are produced by the above Colombian galvanizer company, the kinetic Monte Carlo method were used to simulate an annual production of 41'379.264 items. Additionally, a sample size of 100 was used, meaning that the simulation was run 100 times in order to represent 100 years of production of the above galvanizer. Additionally, 80% was arbitrarily selected as minimum admissible value for all indicators for the study case.

#### 4. Results and discussion

Table 2 presents the relative weights of categories and indicators. These were obtained as a result of the answers of 10 surveyed coating industry and/or industrial sustainability experts. It is possible to notice that economy and quality categories have the highest importance due to a consensus between stakeholders, in contrast to energy usage

whose weight was the lowest. Moreover,  $AAE$  (Actual Atom Economy) and  $SH_{at}$  (Acute Toxicity) metrics are the most important for efficiency and environment, respectively.

Table 2. Relative weight both categories and indicators obtained by means of FAHP (Hernández-Betancur, 2018).

Category	Relative Weight/ Category	Indicator	Relative Weight/ Indicator
Economy	0.2500	Manufacturing Cost ( $COM$ )	1.0000
Quality	0.3134	Zinc Coating Thickness ( $\delta$ )	1.0000
Energy	0.1163	Specific Energy Intensity ( $R_{SEI}$ )	1.0000
Efficiency	0.1770	Actual Atom Economy ( $AAE$ )	0.8116
		Environmental Factor ( $E$ )	0.0440
		Recycled Material Fraction ( $W_{RM}$ )	0.0078
		Total Water Consumption ( $V_{WT}$ )	0.1366
Environment	0.1433	Acute Toxicity ( $SH_{at}$ )	0.1760
		Air Hazard ( $EH_{air}$ )	0.0608
		Water Hazard ( $EH_{wat}$ )	0.0504
		Global Warming Potential ( $GWP$ )	0.0382
		Photochemical Oxidation Potential ( $PCOP$ )	0.0928
		Atmospheric Acidification Potential ( $AP$ )	0.1450
		Polluted Liquid Waste Volume ( $V_{l-poll}$ )	0.1258
		Specific Hazardous Solid Waste ( $m_{HS-s}$ )	0.0311
		Specific Solid Waste Mass ( $m_{s-s}$ )	0.0896
		Specific Liquid Waste Volume ( $V_{l-spec}$ )	0.0168
		Recycling Mass Fraction ( $\omega_{s-recy}$ )	0.1735

On the other hand, in Figure 4, the uncertainty degree of each expert associated to the decision-making process when they decided the relative importance of categories as well as environment and efficiency indicators, is presented. According to Figure 4, expert 6 has the highest uncertainty while expert 5, the lowest. Consequently, the former's answers have more information and his/her personal scores have more relevance in the final result. The opposite occurs with the latter. Here, the amount of information is associated to the amount of uncertainty, as it is considered in Shannon's information theory.

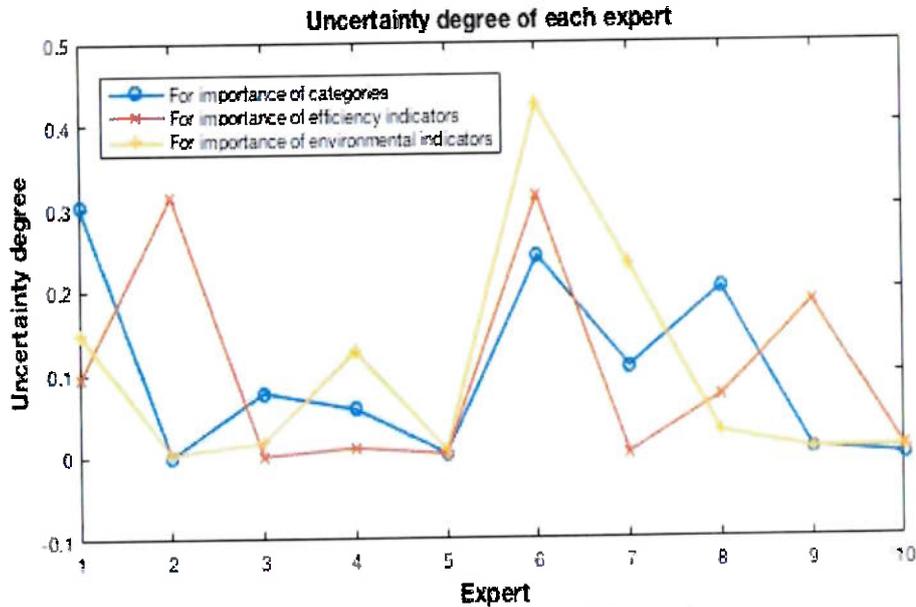


Figure 4. Uncertainty degree of each expert at decision-making moment (Hernández-Betancur, 2018). The blue curve is to represent the uncertainty degree of each expert when the relative importance of each category was established while the red and yellow ones are for the same aspect, but for establishing the weights for all sustainability indicators inside environment and efficiency categories.

Meanwhile, as it was explained before in Figure 1, it is not only necessary to establish the relative weights of sustainability indicators and categories, but also the mass and energy balances associated to each unit process of HDG. For that purpose, the simulation, which was outlined in section 3, was used. With the full process inventory, the 17 indicators selected from GREENSCOPE were calculated for each HDG stage. After that, the process utility,  $U_{p,s}$ , was calculated for each simulation run. The simulation (representing one year of operation) was replicated 100 times in total. Finally, the statistical tools explained in section 2.4 were used to estimate the confidence interval for the process utility mean as it was illustrated in equation 9. The confidence interval obtained is used for assessing the probability of the process for achieving a sustainability state with a minimum admissible value of 80% for all indicators. Furthermore, for all indicators, the mean was used as measure of central tendency and standard deviation was used to display the dispersion observed in the 100 simulation runs for each indicator at the critical stages.

Therefore, in Figure 5, it is possible to observe that stage 6 ( $U_5$ ), fluxing, has the highest relative contribution to the total variance in HDG sustainability, with 67.82%, followed by stages 3 and 4 ( $U_3$ ), pickling (normal and dezincification), with 20.91%. In addition, rinsing steps ( $U_2$  and  $U_4$ ) and drying ( $U_6$ ) had a negligible effect on the variance in process sustainability. Moreover, in Figure 6 the results of a hypothesis test are plotted using a confidence level of 99% and 99 degrees of freedom, for testing the significance of the contribution of each stage to the process sustainability variance. According to the results, stages 1, 3, 4 and 5 ( $U_1$ ,  $U_3$  and  $U_5$ ), which correspond to degreasing, pickling

(normal and dezincification) and fluxing, respectively, exceed the critical value of the test, 0.065784, which was obtained by equation 11. Therefore, according to this method, stages 1, 3, 4 and 5 correspond to the critical points of this specific HDG process.

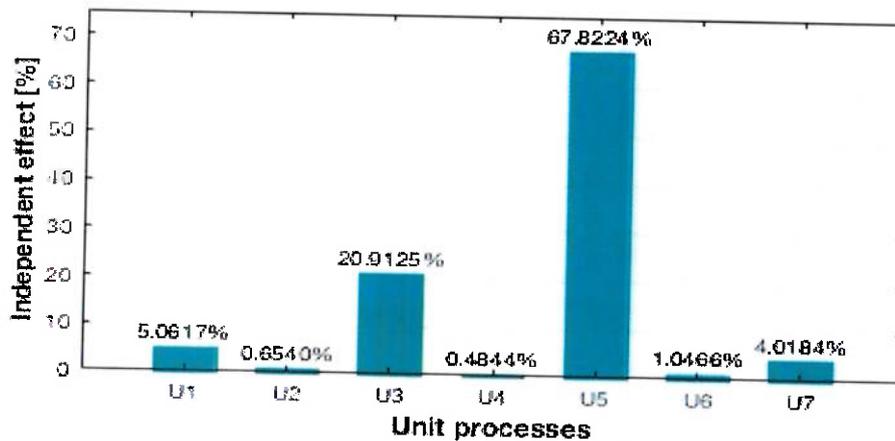


Figure 5. Relative independent effect of each unit process upon the global sustainability variance of HDG process (Hernández-Betancur, 2018).

In contrast, based on a Pareto analysis, pickling (normal and dezincification) and fluxing are considered as the critical points of this HDG process, because the sum of pickling and fluxing contribution is 88.73%. So, the 80% line is exceeded (red line in Figure 7). Thus, considering both the hypothesis test and Pareto analysis, with the purpose of using these methods synergistically, as it stated above, pickling and fluxing are considered the critical stages.

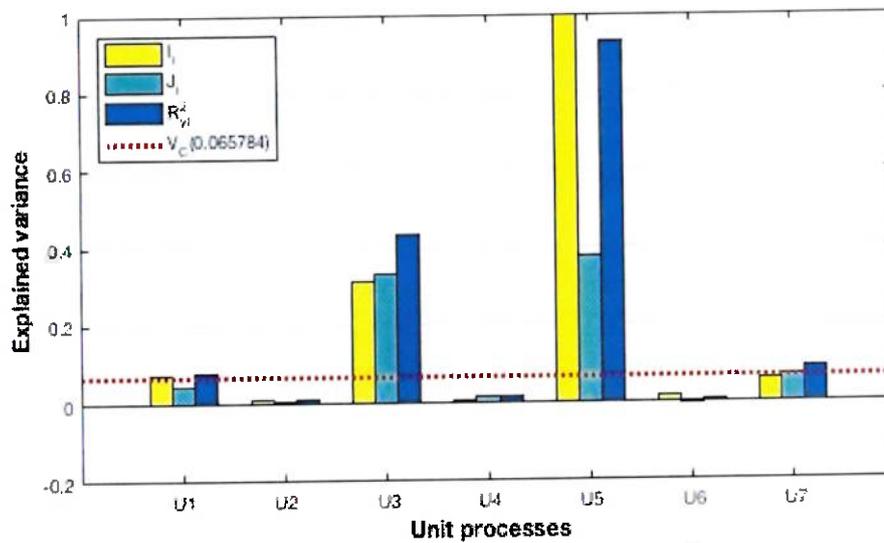


Figure 6. Results of Student's t-test with 99% confidence level and 99 degrees of freedom, for determining the statistical significance of the independent contribution of each unit process on HDG sustainability variance (Hernández-Betancur, 2018).  $I_i$ s are the independent effects of each unit process while  $J_i$ s are their joint ones and  $R_{y_i}^2$ s are the sums between  $I_i$ s and  $J_i$ s; however,  $I_i$ s and  $J_i$ s were normalized by the highest  $I_i$  as it was explained before.

It is also interesting to check Table 3, for noting that the critical points selected above do not only have the highest independent effect under the process sustainability variation, but also, they have the lowest utility. Moreover, the critical points do not exceed the minimum admissible value (80%) and it is not probably to surpass this according their little standard deviations.

Table 3. Mean and standard deviation of each process' stage.

Stage	Utility (%)	Utility scale adjusted (%)
Degreasing ( $U_1$ )	43.60±0.08	63.50±0.11
Rinsing 1 ( $U_2$ )	58.06±0.00	84.57±0.00
Pickling + Dezincification ( $U_3$ )	41.08±0.02	59.82±0.02
Rinsing 2 ( $U_4$ )	58.06±0.00	84.57±0.00
Fluxing ( $U_5$ )	34.41±0.34	50.12±0.50
Drying ( $U_6$ )	58.26±0.02	84.86±0.02
Galvanizing ( $U_7$ )	42.09±0.04	61.30±0.06

On one hand, the bright red cells on the table represent the critical points which was synergistically found by HPA and Pareto's principle. On the other hand, the third column represents the unit process utilities adjusted to 100% for avoiding confusion and allowing comparisons with the minimum admissible value (80%), since unit process utility cannot be higher than 68.66% due to the mathematical procedure to obtain the equation 5 and the relative weight of quality category of 0.3134.

The second column of Table 4 presents the sustainability indicators for the HDG process. As it can be seen in the table, the mean score of the following metrics are not above the admissible value (80%):  $GWP$ ,  $V_{l-poll}$ ,  $m_{S-S}$ ,  $V_{l,spec}$ ,  $\omega_{s,recy}$ ,  $AAE$ ,  $W_{RM}$ ,  $V_{WT}$  and  $COM$ . Additionally, nearly all the above-mentioned indicators do not have a great variation according to the standard deviation of these, hence it is not expected that these can improve without an appreciable change in the process configuration.

Now, third and fourth columns of Table 4 show the average values of all sustainability indicators and their standard deviation for the critical unit processes, pickling and fluxing. So, according to the column three, it can be clearly seen that in order to improve HDG process sustainability at the pickling stage, it is critical to increase the low scores of  $V_{l,spec}$ ,  $V_{l-poll}$ ,  $AAE$ ,  $W_{RM}$ ,  $V_{WT}$  and  $COM$ .

On the other hand, at the fluxing stage the focus should be on increasing the indicator scores for  $GWP$ ,  $V_{l-poll}$ ,  $m_{S-S}$ ,  $V_{l,spec}$ ,  $\omega_{s,recy}$ ,  $AAE$ ,  $W_{RM}$ ,  $V_{WT}$  and  $COM$ . Based on column four of Table 4, there is not a great variation in the indicators as well, and atypical values are not high enough to exceed 80%, the admissible value.

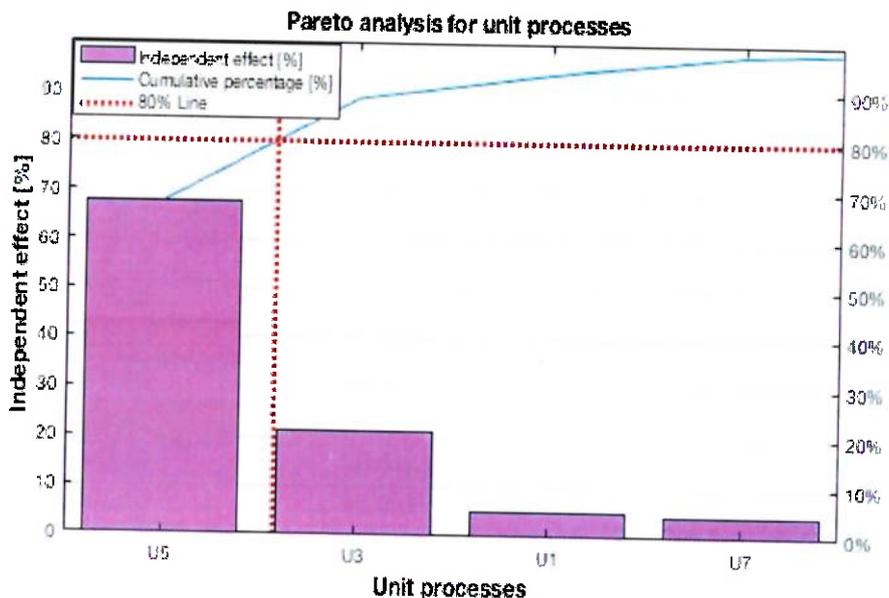


Figure 7. Pareto analysis to determine the importance of the independent contribution of each unit process on HDG sustainability variance (Hernández-Betancur, 2018). The red line is 80% line, the blue curve is the cumulative

percentage and bright purple blocks are independent effect of each unit process.

Finally, from the data obtained, it is possible to say that the probability of the process being sustainable, under the admissible value of the process utility, is 45.26% which was estimated with equation 7. Moreover, with a significance level of 5%, the confidence interval for the process mean utility is  $[1.6409 \times 10^4 \mu m; 1.6982 \times 10^4 \mu m]$  (or [77.8341%;80.5532%]). From the simulation, it was possible to find that the admissible value of the process utility is  $1.6865 \times 10^4 \mu m$  (or 80%). Thus, it can be expected with a confidence level of 95%, that the process utility for this specific system is equal, on average, to the acceptable minimum measure. Additionally, if the variation of the process utility is kept constant, the minimum and maximum values of the probability of the process being sustainable will be 37.67% and 52.93%, respectively.

Table 4. Mean and standard deviation of indicators for global process, pickling and fluxing stages.

Indicator	Indicator score (%)		
	Global process	Pickling	Fluxing
$SH_{at}$	99.97±0.00	99.96±0.00	100.00±0.00
$EH_{air}$	99.70±0.00	99.99±0.00	100.00±0.00
$EH_{wat}$	100.00±0.00	100.00±0.00	100.00±0.00
$GWP$	44.30±0.20	100.00±0.00	9.00±1.00
$PCOP$	99.89±0.00	99.26±0.02	99.98±0.01
$AP$	100.00±0.00	100.00±0.00	100.00±0.00
$V_{t-poll}$	57.35±0.02	0.22±0.01	0.00±0.00
$m_{HS-S}$	85.71±0.00	100.00±0.00	100.00±0.00
$m_{S-S}$	57.14±0.00	100.00±0.00	0.00±0.00
$V_{Lspec}$	40.21±0.02	0.22±0.01	0.00±0.00
$\omega_{s,recy}$	57.14±0.00	100.00±0.00	0.00±0.00
$AAE$	55.30±0.08	2.00±0.10	2.70±0.40
$E$	99.99±0.00	100.00±0.00	99.98±0.00
$W_{RM}$	25.88±0.01	0.36±0.02	0.00±0.00
$V_{WT}$	39.81±0.00	0.00±0.00	0.00±0.00
$R_{SEI}$	91.90±0.30	100.00±0.00	78.00±2.00
$COM$	64.39±0.00	64.39±0.00	64.39±0.00
$\delta$	99.73±0.00		

The bright red cells on the table are those indicators whose score does not exceed the minimum admissible value selected for the study case (80%).

## 5. Conclusions, recommendations and future perspective

For the case of study, according to the holistic framework proposed for analyzing sustainability, the process studied presents a probability of 45.26% to exceed the minimum admissible value of the utility (80%). At a confidence of 95% and 99 degrees of freedom the global utility of the process is in [77.8341%;80.5532%]. Thus, at a significance of 5%, the utility of the process can be expected to be equal to the minimum accepted value of 80%. For this particular process the pickling and fluxing stages are critical, and they could not be improved without changes in their configuration.

On the other hand, about the holistic framework, the methodology allows to detect the critical unit processes and the physical and chemical phenomena to which special attention must be paid. This allows incorporating aspects related to local legislation, thanks to the use of GREENSCOPE. Moreover, it also allows estimating the epistemic uncertainty associated with the decision makers, as well as the random uncertainty of the process itself. Furthermore, it is flexible enough to be extended to other processes and incorporate other indicators related to technical requirements. The methodology is relevant to evaluate processes regardless of whether their configuration is serial or parallel, thanks to the nature of the integrated procedures for multiobjective decision-making, calculation of relative weights and the different statistical tools used in the analysis. The incorporation of laws for the conservation of matter and energy to obtain the life cycle inventory at the spatio-temporal scale of study, whether through a real or simulated process, guarantees the feasibility of the process under natural laws.

Based on the assumptions used in the present investigation, the following recommendations are made: (a) it is recommended for the calculation of the relative weights of categories and indicators, to take a larger sample that covers a wider spectrum of stakeholders such as production operators, the community next to the production plant, environmental entities and others. (b) In the case of implementing the methodology with the simulation of a particular process, it would be very useful to use it under the fact that there is a probability that the steel to be galvanized will be reactive. Thus, affecting in a marked way the thickness of the zinc coating that will be obtained. (c) The methodology opens the possibility of including other relevant indicators for the galvanizing industry, apart from what is illustrated in ISO 1461. For this reason, one can think of incorporating standards that specify the pre-galvanizing and post-galvanizing. (d) The incorporation of an analysis of epistemic uncertainty associated to the parameters used in the calculation of the indicators, should be taken into account in future works that implement the methodology proposed here, being valid as it is proposed by the family of ISO 14040, a sensitivity analysis in the interpretation phase of results. (e) In case of using the methodology in parallel to a simulation of a particular process, it is recommended to conduct a study of the epistemic uncertainty associated with simulation mimicry, in order to rule out possible bias on the part of the simulation, or alternatively to perform a pre-verification of the model. (f) It is recommended for the development of future works, to implement the methodology in a different programming language, to avoid the computational limitation presented in this work, allowing to analyze the critical processes under the hierarchical partitioning analysis philosophy; similar, as was done with the global process in this investigation, and thus, to be able to obtain the independent contributions of each indicator to the sustainability of the critical stage. Alternatively, the same program can be used if there is a cluster of computers. (g) Although it is out of focus of this research, it is recommended the development of a mathematical model of hot dip galvanizing, at a scale that allows us to use mimicry for an analysis like the one done in this work. (h) It is recommended for future work to involve a study of the relation of the scope of the sustainability of the production process and its contribution to the 17 sustainable development objectives.

This investigation opens the door to continue with investigations that incorporate the analysis in the following topics: (a) using the additive utilities method with marginal rates of variable substitution, that is, without using the assumption that the compensation ratio between indicators and categories is perfect. (b) Although the proposed methodology allows to identify the critical points of the process, it has as limitation the fact of how to

make the variations in each unit process without affecting the performance of the others. For this reason, it is suggested to focus studies on how the joint effect calculated by the analysis of hierarchical partitions is generated. (c) Carrying out investigations to establish the way in which the process units are related to obtain the global capacity of the production line to reach a state of sustainability.

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# Carbon footprint of the hot-dip galvanisation process using a life cycle assessment approach

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## ABSTRACT

This work presents the carbon footprint (CF) of two hot-dip galvanisation (HDG) installations located in Spain with differences in the galvanising capacity and in the manufacturing process. The study determines the influence of the direct emissions (scope 1), emissions from electricity production (scope 2), and indirect emissions from upstream and downstream processes (scope 3). The results showed that steel and primary zinc production were the principal contributors to the CF. So, efforts should be focused on reducing the impact of the raw material production included in scope 3. Furthermore, two sensitivity analyses are presented: i) the production of one kg of two types of zinc products, special high-grade and redistilled zinc; ii) the use of two coatings: zinc for galvanisation and paint for pre-printed steel. The environmental impacts in SHG zinc were higher than in redistilled zinc, for all the impact categories due to the great influence of heavy metals emission. The results for zinc and paint protections showed that under the same level of corrosion, a greater thickness of paint is needed to protect steel pieces, compared to zinc coating. This sustainability assessment of the HDG industry recommends the sought of technology alternatives aimed at resource efficiency, such as zinc recovery from spent pickling baths, that could provide the desirable reduction of the environmental impacts associated to primary resource usage and waste treatment.

## 1. Introduction

### 1.1. The hot-dip galvanising process

World crude steel production reached 1868.8 Mt in 2019 (Fig. 1), showing an increasing trend since the 90s that was only interrupted by the economic crisis of 2009. China was the main producer in 2019 with 996.3 Mt of steel, more than half of the worldwide production (51.3%), while Europe accounted for 8.5% in the same period, Spain representing the 17th global position and the 4th position at the European scope with 13.6 Mt of crude steel produced in 2019 (World Steel Association, 2019). Steel production requires a great amount of energy and extraction of non-renewable resources, mainly iron. Specifically, the steelmaking industry is the largest energy consumer in the world, and almost 27% of the global CO<sub>2</sub> emissions are derived from this sector (Jaimes and Maroufi, 2020). Some measures to reduce greenhouse gases (GHG) emissions from the steel industry are scrap recycling, the use of carbon free-energy, and the production of high-performance steel to extend its lifespan and to reduce steel corrosion that generates relevant monetary losses (Fresner et al., 2007). Scrap recycling reduces GHG emissions since the impacts of

using one kg of scrap to produce steel are much lower than those of one kg of pig iron, as scrap does not go through the stages of mining, refining, and melting (Tongpool et al., 2010).

Regarding steel protection, zinc coating protects steel from corrosion by the formation of a passive layer that simultaneously provides a sacrificial anode (Nakhaie et al., 2020). The durability of protection depends on the zinc layer thickness and the environmental exposure conditions (Kovalev et al., 2019). The hot-dip galvanising (HDG) method is one common and effective solution to protect steel structures from corrosion. The negative aspects of the galvanising industry include the intensive use of energy and primary zinc (Urtiaga et al., 2010). Fig. 1 shows that crude steel production is clearly linked to zinc production, the latter accounting for one-hundredth of steel production. Although zinc represents a low percentage by weight of galvanised steel components, the environmental burdens of zinc are distinctively high. Tongpool et al. (2010) evaluated the production of both steel and primary zinc, using some impact categories such as Abiotic Depletion of fossil fuels (ADP-fossil), Abiotic Depletion of elements (ADP-elements) and Global Warming Potential (GWP). The impacts of zinc production were always higher than the impacts of steel production, e.g.: almost three times higher for ADP-fossil, more than one hundred times greater in

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Abbreviations			
ADP-elements	Depletion of Abiotic Resources-Elements	GWP	Global Warming Potential
ADP-fossil	Depletion of Abiotic Resources-Fossil	HDG	Hot-dip galvanising
AP	Acidification Potential	HTP	Human Toxicity Potential
BSI	British Standards Institution	LCA	Life Cycle Assessment
CF	Carbon Footprint	MAETP	Marine Aquatic Ecotoxicity Potential
C2	Corrosivity category of low level	ODP	Ozone Layer Depletion Potential
C3	Corrosivity category of medium level	POCP	Photochemical Ozone Creation Potential
EP	Eutrophication Potential	SHG zinc	Special high-grade zinc
FAETP	Freshwater Aquatic Ecotoxicity Potential	SPA	Spent Pickling Acid
FU	Functional unit	TETP	Terrestrial Ecotoxicity Potential
GDP	Gross Domestic Product	ULCOS	Ultra Low CO <sub>2</sub> Steelmaking
GHG	Greenhouse gas	WRI	World Resources Institute
		WBC SD	World Business Council for Sustainable Development

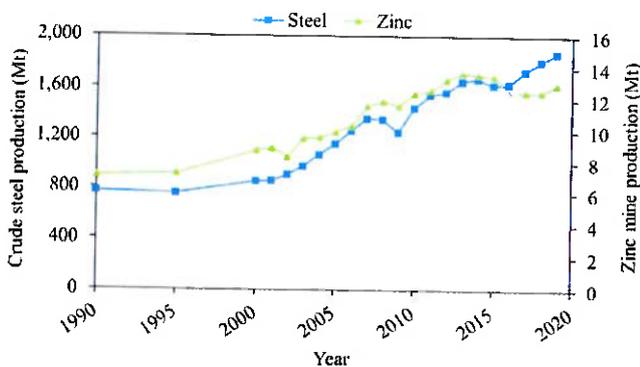


Fig. 1. Crude steel and primary zinc productions. Data taken from (United States Geological Survey (USGS), 2019; World Steel Association, 2019).

ADP-elements, and three times higher in the case of GWP. Thus, one important challenge of the galvanisation sector, is to reduce its environmental impacts linked to the intensive use of energy and resources.

### 1.2. The hot-dip galvanising process and life cycle assessment

In the literature, the environmental assessment of steel production has been studied using tools such as life cycle assessment (LCA). Liu et al. (2020) used LCA methods to assess the impacts of five iron top-mining countries and ten steel top-producing countries. Results concluded that toxicity impacts were the most crucial consequences of this sector, even higher than the impacts of CO<sub>2</sub> emissions. The European initiative "Ultra Low CO<sub>2</sub> Steelmaking (ULCOS)" to reduce CO<sub>2</sub> emissions by 50% by 2050, enables the use of LCA to compare alternative metallurgical technologies (Burchart-Korol, 2011). Previous works have evaluated the environmental impacts of different products that employ a zinc coating for corrosion protection. Bolin and Smith (2011) performed the environmental comparison between borate-treated lumber used as structural framing with galvanised steel framing members. Cambria and Pierangeli (2012) identified the hot spots of high-quality timber production from a dedicated walnut tree plantation that includes galvanised steel components for plants protection. Ansah et al. (2020) compared the environmental and economic burdens of different facade systems in low-cost residential buildings in Ghana, one of them being the galvanised steel insulated facade. However, few studies have investigated the environmental performance of HDG processes. This factor indicates the need to evaluate the galvanisation process by means of environmental tools to provide insights into the environmental sustainability of HDG. Spain is the fourth country in installed capacity and production in the Eurozone,

and galvanised steel production was 15% higher in 2019 than in the previous year, reaching  $650 \cdot 10^3$  t/y (Spanish Technical Association of Galvanisation, 2020). This sector also takes economic importance since corrosion costs represent 4% of the national Gross Domestic Product (GDP), which implies more than  $40 \cdot 10^3$  MEUR/y. In Spain, the HDG sector consists of 43 small and medium-size facilities with profits higher than 200 MEUR/y and with more than 3000 direct jobs (Spanish Technical Association of Galvanisation, 2020). Galvanised steel is mostly consumed by the energy generation and distribution sector (40%), followed by building and construction, which uses 25% of the total production. Other common applications are road elements, industrial equipment, and transport.

There is a higher worldwide trend of simplification focusing on a single indicator, carbon footprint (CF) that is relevant to global warming (Kosai and Yamasue, 2019). CF can be assessed at product or corporate level. Product CF follows LCA methodology, but analyses only the impact in terms of kg CO<sub>2</sub> eq., and it is based on standards such as ISO 14067 (2013), PAS 2050 (BSI, 2011) or GHG Protocol for products (WRI and WBC SD, 2011a). CF at corporate level is carried out following the standards ISO 14064 (2006) or GHG protocol (WRI and WBC SD, 2004). In the same vein as the LCA and the HDG process, there is a gap in the literature on adopting a carbon footprint approach for the galvanising sector.

### 1.3. Aim of the study

This study aimed to evaluate the environmental performance of the HDG sector in Spain, based on data from two HDG plants, which are very representative of the galvanising sector of the country in order to identify the contribution of each scope to the total carbon footprint in both facilities. Through the total CF is possible to place these plants within the Spanish galvanising sector and reach conclusions about the consequences of the differences between both facilities. CF was calculated at three scopes: 1) direct emissions, 2) emissions from electricity production and 3) indirect emissions from upstream or downstream processes. Considering the influence of resource use, two sensitivity analyses were conducted. In the first analysis, the production of two types of primary zinc was assessed. Secondly, primary zinc production was compared with the production of paint used as corrosion protective coating of steel structures. The analysis of zinc production included other impact categories in addition to the CF to consider the toxicity of zinc mining and refining, as the impact categories related to toxicity should be considered (Liu et al., 2020).

This paper constitutes the first Corporate Carbon Footprint of the HDG process based on two Spanish HDG plants. The analysis including the three CF scopes allows to identify the hot spots of the HDG process focusing on a single indicator relevant to global warming, which adds a simplification to the analysis and interpretation of the results. In

addition, the sensitivity analysis of zinc production, and the comparison between zinc and paint production could provide significant improvements to the HDG sector.

## 2. Methodology

Carbon footprint based on ISO 14064 (2006) and GHG corporate protocols (WRI and WBC SD, 2011b) was used to determine the GHG emissions of two HDG plants located in Spain. CF measures the total GHG emissions that are directly and indirectly caused by a human activity, including those accumulated over the life stages of a product (Clabeaux et al., 2020). World Resources Institute (WRI) and World Business Council for Sustainable Development (WBC SD) define three scopes. Scope 1 includes direct GHG emissions from sources that are owned or controlled by the company. Scope 2 refers to the upstream emissions from the generation of purchased electricity, and scope 3 comprises indirect GHG emissions that are a consequence of the company's activities. Scope 3 can be divided in upstream (raw materials extraction and its transportation), and downstream processes (waste management). Scope 3 can be excluded in the corporate CF produced by companies, albeit, the present work includes those indirect emissions. Life cycle methodology following ISO 14044 (2006) is used to quantify indirect emissions included in the scopes 2 and 3 (Navarro et al., 2017). In this work, indirect emissions were calculated by questionnaires completed by the companies for 2016 and 2017. The HDG plants under study, HDG plants #1 and #2, are referred as scenarios 1 and 2 throughout this study. The data inventory for both scenarios is shown in Table S1.1 as Supplementary Material. Secondary data come from Sphera (professional database 2020) and Ecoinvent (version 3.6) databases (Ecoinvent, 2020; Sphera, 2020). The reference unit used has been defined as the production of one tonne of galvanised steel. This can be considered as the functional unit (FU) although in Corporate Carbon Footprint studies there is no functional unit (Navarro et al., 2017). Carbon footprint is focused on a single indicator relevant to global warming, which is measured in kg of CO<sub>2</sub> equivalent emissions. CML 2001 updated in 2016 has been selected to include other impact categories for the sensitivity analysis of primary zinc production. These impact categories are: abiotic depletion of elements (ADP-elements) [kg Sb eq.], abiotic depletion of fossil fuels (ADP-fossil) [MJ], acidification potential (AP) [kg SO<sub>2</sub> eq.], eutrophication potential (EP) [kg PO<sub>4</sub><sup>3-</sup> eq.], freshwater aquatic ecotoxicity potential (FAETP) [kg DCB eq.], human toxicity potential (HTP) [kg DCB eq.],

marine aquatic ecotoxicity potential (MAETP) [kg DCB eq.], photochemical ozone creation potential (POCP) [kg ethene eq.], and terrestrial ecotoxicity potential (TETP) [kg DCB eq.].

### 2.1. System boundaries

Fig. 2 describes the flow diagram and system boundaries of the industrial installations that have been named as scenario 1 and scenario 2. The differences between the two HDG facilities (scenarios 1 and 2) are explained in section 2.2. The scope of the study included the extraction of resources, the production of raw materials including steel, their transport to the galvanising plants, the galvanisation process itself, waste treatment and transport to waste management facilities, and its final disposal. The usage and end-of-life phases of the galvanised steel were not included. Buildings and machinery were excluded from this analysis since their environmental impacts were very small compared with the impacts of steel production and the HDG process (Heinonen et al., 2016).

Within the HDG process the main stages were degreasing, pickling, fluxing, drying, immersion in the molten zinc bath and centrifugation (Ortiz et al., 2004). The main raw materials inputs are primary zinc and hydrochloric acid. Primary zinc is used in the molten zinc bath where steel pieces are immersed to acquire the zinc coating. Hydrochloric acid is employed in the pickling stage to remove impurities and oxides from the surface of steel pieces. Natural gas is the main energy vector in both scenarios, although electricity is also consumed. Natural gas is employed to produce thermal energy that is used to dry the steel pieces before their immersion into the molten zinc bath. The degreasing and pickling baths also require heating, but to a much lesser extent (European Commission, 2001). Spent pickling acids (SPAs) are one of the most relevant wastes that are generated in the HDG process. SPAs are usually handled in external waste management facilities by a physicochemical treatment whose outputs are treated water and hazardous sludge, the latter once stabilised is sent to a non-hazardous waste landfill (Devi et al., 2014). Both scenarios also generate other important residues, identified as ashes and dross, both with high content of metallic zinc (Rudnik, 2019). Ashes and dross are valorised to produce secondary zinc and/or zinc oxide, following processes that are not included in this study (Negrea et al., 2017). Direct emissions from natural gas extraction and its combustion to produce thermal energy are included in the scope 1. The indirect emissions from purchased electricity is covered by the scope 2. The production of raw materials and their transport to the HDG plants are upstream

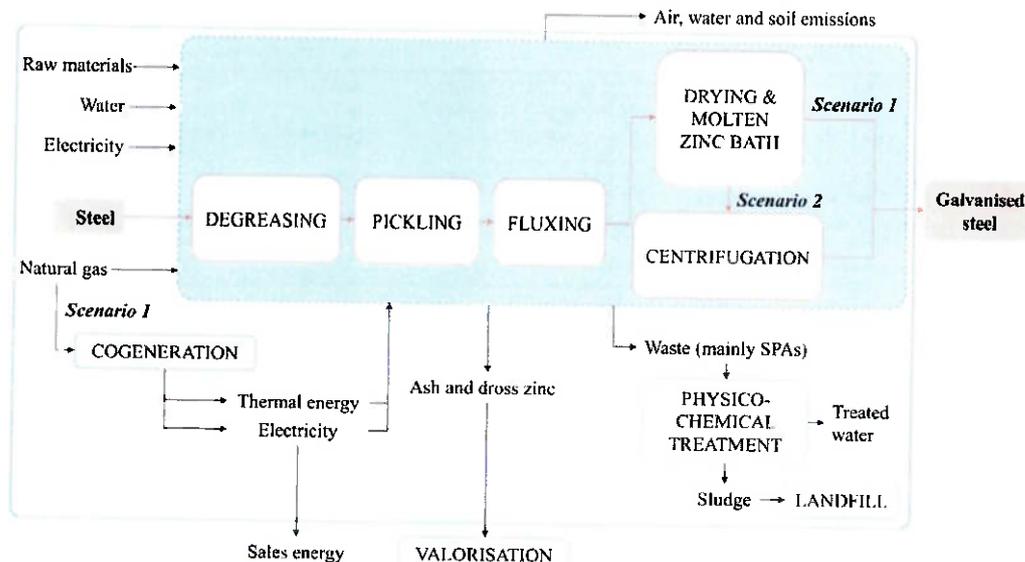


Fig. 2. System description of the hot-dip galvanisation process in scenarios 1 and 2.

processes that belong to scope 3. Finally, waste management and disposal on landfill and their transport are downstream processes of scope 3. The production of ZnCl<sub>2</sub> and NH<sub>4</sub>Cl salts used in the fluxing stage and zinc alloys added in the molten zinc bath have been excluded from the study. This exclusion is based on the cut-off criteria, which established that the material flows that are excluded must not exceed 1% of the mass of each unit process and the sum of all excluded material flows in the system must not exceed 5.0% of the total mass flux.

### 2.2. Description of scenarios

Both scenarios have the same purpose, that is to galvanise steel pieces by the HDG process in a discontinuous way. Next, we explain the differences between the two scenarios.

**Scenario 1.** The galvanising capacity of scenario 1 was 51.4·10<sup>3</sup> and 78.7·10<sup>3</sup> t galvanised steel/y in 2016 and 2017. Steel pieces are mostly employed for building and civil infrastructure. Scenario 1 presents a cogeneration unit to produce thermal energy and electricity to supply the energy of drying and baths heating. All the thermal energy and one part of the electricity is employed in the galvanisation process, but a relevant portion of the electricity is sold to the grid mix obtaining potential benefits.

**Scenario 2.** Scenario 2 has a galvanisation capacity of 3.5·10<sup>3</sup> and 4.85·10<sup>3</sup> t galvanised steel/y in 2016 and 2017. Steel pieces are smaller in size, and are employed in the manufacturing of machinery, e.g.: in the assembly of wind turbine structures. This causes the incorporation to the HDG process of an additional centrifugation stage in order to remove excess of liquid zinc from galvanised pieces. One of the main differences between both scenarios is that scenario 2 does not incorporate cogeneration.

### 3. Results and discussion

The results obtained in the present study represent the environmental impacts of both scenarios for 2016. Table 1 summarises results from 2016 to 2017, where it can be observed that the outcomes were similar in the consecutive years, a consequence of the inventory being practically stable.

**Table 1**  
Carbon footprint (kg CO<sub>2</sub> eq./t galvanised steel) for scenarios 1 and 2.

	kg CO <sub>2</sub> eq./t galvanised steel				Contribution to the total CF (%)			
	Scenario 1		Scenario 2		Scenario 1		Scenario 2	
	kg CO <sub>2</sub> eq./FU				%			
	2016	2017	2016	2017	2016	2017	2016	2017
Natural gas	166.70	151.65	191.06	159.70	9.30	8.50	12.9	11.3
Propane	9.33·10 <sup>-2</sup>	7.73·10 <sup>-2</sup>	-	-	5.20·10 <sup>-3</sup>	4.35·10 <sup>-3</sup>	-	-
Electricity	2.44·10 <sup>-1</sup>	8.74·10 <sup>-2</sup>	32.30	23.30	1.36·10 <sup>-2</sup>	4.92·10 <sup>-3</sup>	2.2	1.6
Steel	1440	1440	1020	1022	80.2	81.1	69.0	72.2
Zinc	163.98	158.66	220.43	202.72	9.1	8.9	14.9	14.3
HCl	10.40	10.81	3.73	2.83	5.79·10 <sup>-1</sup>	6.09·10 <sup>-1</sup>	2.52·10 <sup>-1</sup>	2.00·10 <sup>-1</sup>
Wire	3.76	4.44	-	-	2.09·10 <sup>-1</sup>	2.50·10 <sup>-1</sup>	-	-
H <sub>2</sub> O <sub>2</sub>	3.31	2.15	0.34	0.18	1.84·10 <sup>-1</sup>	1.21·10 <sup>-1</sup>	2.29·10 <sup>-2</sup>	1.25·10 <sup>-2</sup>
NH <sub>3</sub>	1.57	1.35	1.38	1.71	8.75·10 <sup>-2</sup>	7.63·10 <sup>-2</sup>	9.31·10 <sup>-2</sup>	1.21·10 <sup>-1</sup>
NaOH	1.37·10 <sup>-1</sup>	1.76·10 <sup>-1</sup>	-	-	7.65·10 <sup>-3</sup>	9.89·10 <sup>-3</sup>	-	-
KOH	1.03·10 <sup>-1</sup>	1.32·10 <sup>-1</sup>	-	-	5.74·10 <sup>-3</sup>	7.42·10 <sup>-3</sup>	-	-
Tap water	8.93·10 <sup>-2</sup>	6.81·10 <sup>-2</sup>	9.52·10 <sup>-2</sup>	8.97·10 <sup>-2</sup>	4.97·10 <sup>-3</sup>	3.84·10 <sup>-3</sup>	6.44·10 <sup>-3</sup>	6.33·10 <sup>-3</sup>
Pallets	-1.22	-0.99	-	-	-6.78·10 <sup>-2</sup>	-5.56·10 <sup>-2</sup>	-	-
Wood	-1.73	-2.86	-	-	-9.65·10 <sup>-2</sup>	-1.61·10 <sup>-1</sup>	-	-
HF	-	-	0.14	0.24	-	-	9.54·10 <sup>-3</sup>	1.71·10 <sup>-2</sup>
H <sub>3</sub> PO <sub>4</sub>	-	-	3.50·10 <sup>-2</sup>	3.73·10 <sup>-2</sup>	-	-	2.37·10 <sup>-3</sup>	2.64·10 <sup>-3</sup>
Transport of raw materials	6.94	6.76	1.94	2.91	3.86·10 <sup>-1</sup>	3.81·10 <sup>-1</sup>	1.32·10 <sup>-1</sup>	2.05·10 <sup>-1</sup>
Transport of waste	9.31·10 <sup>-1</sup>	1.72	5.76	0.28	5.18·10 <sup>-2</sup>	9.68·10 <sup>-2</sup>	3.90·10 <sup>-1</sup>	1.97·10 <sup>-2</sup>
Waste management	0.57	0.41	0.28	0.17	3.18·10 <sup>-2</sup>	2.30·10 <sup>-2</sup>	1.91·10 <sup>-2</sup>	1.17·10 <sup>-2</sup>
TOTAL	1795.87	1774.65	1477.49	1416.60	-	-	-	-
Energy credits from cogeneration	-72.60	-57.56	-	-	-	-	-	-
Scrap valorisation	-4.94	-6.00	-	-	-	-	-	-
TOTAL	1718.33	1711.09	1477.49	1416.60	-	-	-	-

### 3.1. Carbon footprint analysis

Fig. 3 shows the contribution in percentage and the total value of the CF (kg CO<sub>2</sub> eq./t steel) in scenarios 1 and 2 for 2016. These results include the valorisation of scrap and the energy credits obtained from cogeneration in the first scenario.

The total CF (as sum of scopes 1, 2 and 3) was 1796 and 1477 kg CO<sub>2</sub> eq./t galvanised steel in scenarios 1 and 2. The total CF is higher in scenario 1 due to the contribution of steel production that will be discussed in Fig. 4. Direct emissions included in the scope 1 are derived from the combustion of natural gas, with a very low contribution of propane in the first plant. The contribution of natural gas is higher in the second scenario (12.9% vs. 9.3%) since the cogeneration unit improves the overall environmental performance of scenario 1. In other words, scenario 1 is more efficient than scenario 2 regarding the obtention of

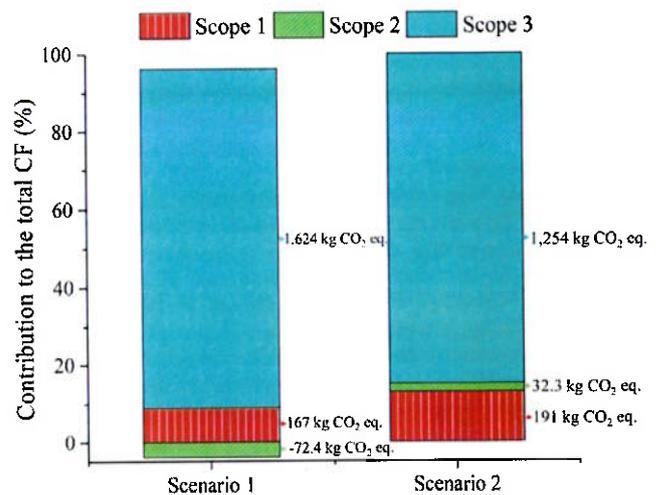


Fig. 3. CF (kg CO<sub>2</sub> eq./t galvanised steel) and contribution of each scope for scenarios 1 and 2 in 2016, including scrap valorisation (scope 3 downstream) and energy credits from cogeneration (scope 1).

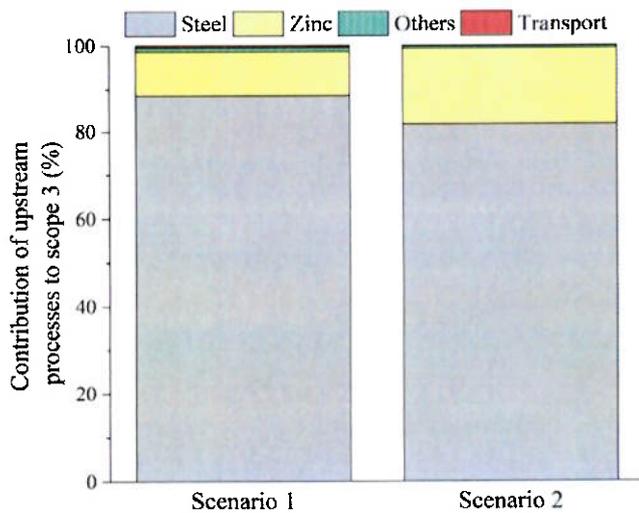


Fig. 4. Contribution of upstream processes for scenarios 1 and 2 in 2016, including scrap valorisation and energy credits from cogeneration.

thermal energy from natural gas. Indirect emissions due to the electricity consumption have a very low contribution to the total CF (0.0014 and 2.2% in scenarios 1 and 2). In both scenarios, the highest impact is attributed to indirect emissions included in the scope 3, with a contribution to the total CF of 91% and 85% in scenarios 1 and 2. The scope 3 is divided into upstream (raw materials) and downstream (waste) processes. The upstream processes represent in both plants more than 99% of the impact of scope 3. In this context, Fig. 4 shows the contribution of the upstream processes for both scenarios separated in steel, zinc, and other raw materials. Other raw materials in scenario 1 are  $\text{NH}_3$ , KOH, NaOH, wood, pallets and tap water. In scenario 2, other raw materials are HF,  $\text{H}_3\text{PO}_4$ ,  $\text{H}_2\text{O}_2$ ,  $\text{NH}_3$  and tap water. Transport of raw materials to the HDG plants is included. Downstream processes represent a very low contribution to the total CF (0.08 and 0.41% in scenarios 1 and 2) as Table 1 shows. In addition, scrap valorisation provides material credits in scenario 1 ( $-4.94 \text{ kg CO}_2 \text{ eq./t galvanised steel}$ ).

As Fig. 4 shows, the CF is linked to the raw materials extraction and manufacturing, with a low influence of the transportation on the overall results. Steel was the main contributor in both scenarios (more than 80% of upstream impact), although this percentage is higher in scenario 1. In the first scenario, the steel sections have a higher CF than the engineering steel applied in the second scenario. The selection of a representative steel has a great influence on the results since steel production is one of the main impacts of the HDG process. In fact, there is a huge variability of impact results for different types of steel. For instance, the CF of "engineering steel", "steel sections", "steel rebar" and "steel plate" is 1, 1.49, 2.29 and  $2.52 \text{ kg CO}_2 \text{ eq./kg steel}$ .

Primary zinc is the other important material in scope 3, accounting for 10–20% of the CF of upstream processes. The contribution of zinc production to the scope 3 was greater in the scenario 2 since its consumption per tonne of galvanised steel is higher. Raw materials production provided in Table 1 denoted its low contribution in both scenarios.

As it was mentioned before, the electricity consumption has a very low contribution to the total CF although it is much higher in scenario 2 than in scenario 1. Concerning other raw materials, the consumption of HCl is much higher in the first scenario, albeit, the contribution to the total CF is only 0.6%. The rest of raw materials has a similar contribution. The CF contribution of the transport of raw materials to the HDG plants is much higher in the first scenario ( $6.96 \text{ vs } 1.94 \text{ kg CO}_2 \text{ eq./t galvanised steel}$  in 2016). This tendency is the contrary for the transport of waste, which is higher in the second scenario in the same year. Besides, the CF caused by waste management is highly dependent by the amount of SPA

generated. Wood and pallets had negative impacts since the CF includes biogenic carbon, meaning that these materials capture and fix carbon dioxide. In case of excluding biogenic carbon, the CF changes from  $-1.22$  to  $0.35 \text{ kg CO}_2 \text{ eq./t galvanised steel}$  for pallets, and from  $-1.73$  to  $1.16 \text{ kg of CO}_2 \text{ eq./t galvanised steel}$  in the case of wood.

### 3.2. Sensitivity analysis of zinc production

Considering the significant contribution of upstream processes to the CF of HDG industrial facilities, this section evaluates the environmental impacts of using two types of primary zinc. The sensitivity analysis presented in this section includes other impact categories based on the CML 2001 impact assessment method.

Fig. 5 shows the environmental impacts for producing 1 kg of special high-grade zinc (SHG) and redistilled zinc. Primary zinc is produced in two consecutive phases, the first one being the production of zinc concentrates that involves mining and beneficiation, followed by the metal zinc production (Van Genderen et al., 2016). Metal zinc production can be carried out by electrometallurgical or pyrometallurgical smelting. The main difference between them is that the electrometallurgical route uses zinc concentrate as input, and the pyrometallurgical route can also use secondary zinc. For this reason, the pyrometallurgical process produces zinc with lower purity than the electrometallurgical route. The electrometallurgical way comprises roasting, leaching, purification, electrolysis and melting. In pyrometallurgical smelting, the unit operations are sintering, smelting, and refining. The smelting furnace is an energy-intensive process that needs of high temperatures to reduce zinc oxide in the presence of coke, to zinc in vapor phase. After the stages of leaching and purification, some metals contained in the ore mines such as lead, copper and cadmium are separated to produce refined metals (Van Genderen et al., 2016). It is estimated that 90% and 92% of the SHG and "redistilled" zinc are obtained by the electrometallurgical route.

The environmental impacts are higher for SHG zinc, compared to the "redistilled" zinc, in all the impact categories except for ADP-elements and ADP-fossil, although the differences in this last category are minimal. GWP and ADP-elements are similar for the two types of zinc. ADP-elements is influenced by the impact of silver, which is a by-product of primary zinc production, but is not considered as such in the Sphera database. Nevertheless, the impact of lead explains the increase of the ADP-elements impact of "redistilled" zinc, which is eight times higher than in SHG production. This can be influenced by the quality of the ore mine, that in case of containing lead could enable the beneficiation of this metal after leaching in the electrometallurgical route (Van Genderen et al., 2016). ADP-fossil and GWP are similar between both types of zinc because the differences between natural gas and hard coal consumption and  $\text{CO}_2$  emissions are minimal. The more relevant differences between both types of zinc are found in HTP and TETP. HTP is much higher for SHG zinc, due to the emission to air of arsenic (+V), cadmium and copper. Cadmium and copper can be obtained after the purification stage in the electrometallurgical route (Van Genderen et al., 2016), and arsenic is a by-product of the smelting of copper, lead and zinc concentrates (Nelson, 1977). The contribution of "redistilled" zinc to HTP is caused by arsine ( $\text{AsH}_3$ ), with negative effects on health, such as cancer and cardiovascular disease that have been associated with long-term exposure to arsenic in humans (Wang et al., 2006). TETP is much higher for SHG zinc because of the mercury emissions to air. The reason is that zinc ore usually contains trace amounts of mercury, that make zinc smelting a relevant source of mercury emissions in the nonferrous metal industry (Takaoka et al., 2017).

EP and FAETP are more than four times higher in SHG zinc than in "redistilled" zinc. The differences in EP are attributed to the emission of nitrogen oxides to air. In both types of zinc, FAETP is motivated by the emission of heavy metals to freshwater, although the difference between both types is due to the copper emissions. AP, MAETP and POCP are almost two times higher for SHG zinc than for "redistilled" zinc. AP and POCP are caused by the emissions of sulphur dioxide and nitrogen oxides

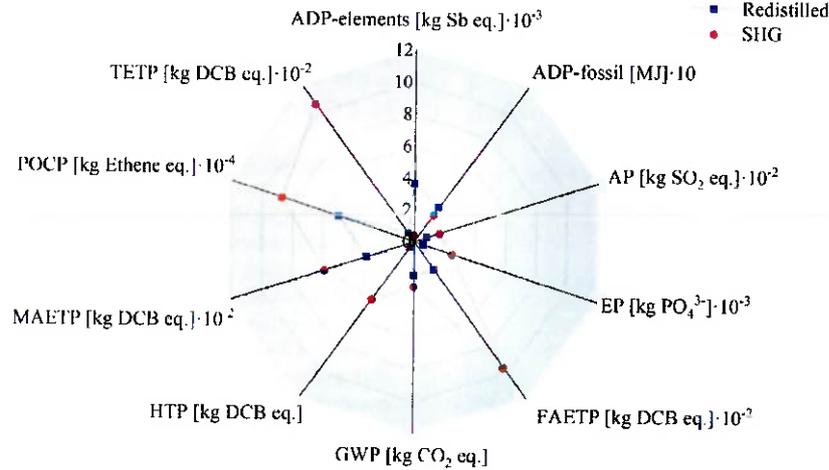


Fig. 5. Sensitivity analysis of the production of one kg of two types of zinc: SHG and “redistilled”.

to air. However, the emissions of NOx to air are more notable in SHG zinc than in “redistilled” zinc. MAETP for SHG and redistilled zinc is motivated by the emission of hydrogen fluoride to air, but for SHG zinc, the additional copper emission to air increases its contribution.

3.3. Comparative analysis of the zinc coating and painting

Zinc production is one of the main environmental impacts of the HDG process in addition to steel production. This section compares the production of zinc and paint to be used as corrosion protection medium for steel. The steps summarised in Fig. 6 have been followed to compare the protective zinc and paint coatings under the same ambient exposure. The classification of the corrosivity of the atmosphere is determined by ISO 9223 (2012), which indicates that C2 and C3 correspond to low and intermediate levels of corrosivity. For comparison, the category C3, which represents atmospheric conditions with intermediate pollution (5–30 µg SO<sub>2</sub>/m<sup>3</sup>), is selected.

The average thickness of the zinc coating under C3 atmosphere, 85 µm, is reported in ISO 1461 (2009). The corrosion rate determined by ISO 14713-1 (2017), declares that under C3 atmosphere the thickness loss is between 0.7 and 2.1 µm/y, before the first maintenance operation is needed. Considering 85 µm thickness of the protective zinc layer and the corrosion rate, the durability of galvanised steel can be estimated between 40 and more than 100 years, which is very high. In the case of the paint coating, the thickness is reported by ISO 12944 5 (2018). Under C3

exposure category, the average thickness of the paint coating should be between 240 and 260 µm to provide steel with very high durability. This means that the first maintenance operation should be carried out after 25 years as ISO 12944-1 (2017) describes. With this information, and the density of zinc and paint, the consumption per m<sup>2</sup> of steel before the first maintenance operation can be calculated. Finally, this consumption should be divided by the durability of each protection coating to obtain the amount of zinc and paint per m<sup>2</sup> of steel for one year of protection. In the case of zinc coating, the durability considered is the average between 40 and 100 years (70 years). With this data, the comparison can be performed. Specifically, a comparison between the two types of zinc explained in section 3.2, which are SHG and “redistilled”, with the production of two types of paints, solvent, and water-based paint white, is shown in Fig. 7. Both types of paints are used for the protection of metals, but their composition differs, and this explains the differences shown in Fig. 7. Solvent paint has 17% binding agent, 16% pigments and fillers, and 67% solvent. Water paint is formed by water varnish, with a composition of 21% binding agent, 35% pigments and fillers, 40% water, and 4% solvent. The fraction of organic solvent employed determines the significantly higher CF differences of solvent paint, 0.040 kg CO<sub>2</sub> eq./m<sup>2</sup> steel for one year of protection, in comparison with the water paint. Water paint and SHG zinc have similar CF, 0.025 and 0.024 kg CO<sub>2</sub> eq./m<sup>2</sup> steel for one year of protection. Redistilled zinc is the protective coating with the lowest CF, 0.018 kg CO<sub>2</sub> eq./m<sup>2</sup> steel for one year of protection. There are water-based coatings that can efficiently protect

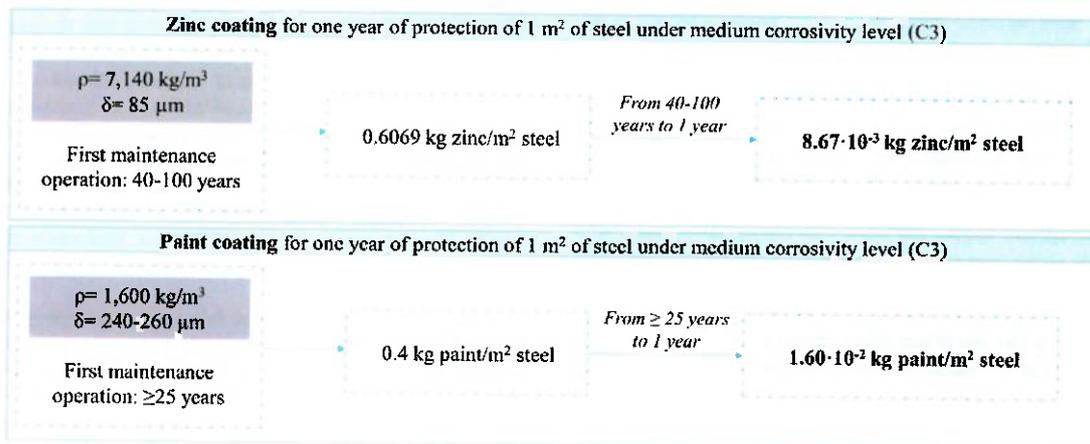


Fig. 6. Steps to perform the comparison between zinc and paint coatings for one year of protection to steel.

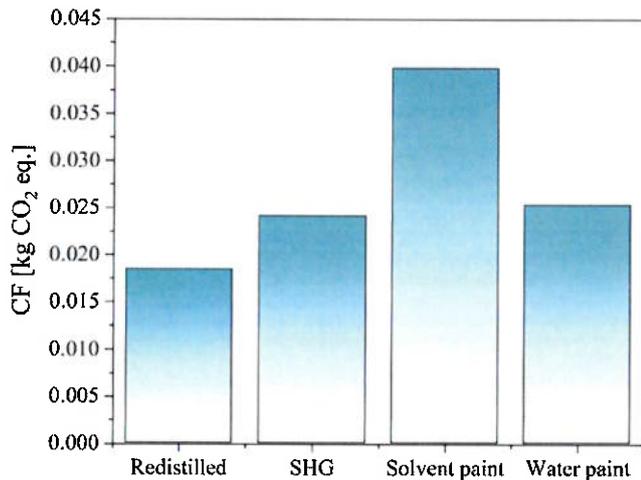


Fig. 7. Carbon footprint (kg CO<sub>2</sub> eq./m<sup>2</sup> steel) of the production of zinc (SHG and redistilled) and paint (solvent and water-based paint) for one year of corrosion protection of steel, and equivalent lifespan.

steel surfaces exposed to aggressive conditions (corrosivity > C5) (Fragata et al., 2006). Nevertheless, paint manufacturing technology, especially in the case of water-based paints, can influence the anti-corrosion performance of paint systems. As a result, similar systems supplied by different manufacturers work in different ways. This uncertainty does not occur in the case of using SHG zinc.

#### 4. Conclusions

This paper presents the corporate carbon footprint of the hot-dip galvanising process, calculated for two HDG industrial installations (scenario 1 and scenario 2) located in Spain. Emissions from the production of steel and primary zinc (considered in Scope 3 of CF calculation) and the consumption of natural gas (Scope 1) were the hotspots of the HDG process with the highest contribution to the total CF. The influence of the purchased electricity (Scope 2) in both HDG plants was very low in comparison with the upstream processes (Scope 3). The energy credits obtained in the scenario 1 by the cogeneration unit improved its CF, albeit, this implementation is not possible in all HDG plants. These energy credits affect to Scope 1, and the material credits from the scrap valorisation have influence on Scope 3. Considering both credits, the total CF of scenario 1 was 1718.33 kg CO<sub>2</sub> eq./t galvanised steel, a 4.32% improvement respect to the calculation of CF without including the energy and material credits (1795.87 kg CO<sub>2</sub> eq./t galvanised steel). The carbon footprint of the HDG process could be mitigated using scrap as raw material in the steel production and increasing the efficiency of primary zinc consumption. Nevertheless, the energy consumption and resultant carbon impacts are limited by the galvanised steel demand that has an increasing trend.

As zinc plays a fundamental role in the reduction of the CF of the HDG process, the environmental impacts of two types of zinc were compared (SHG and redistilled zinc). The production of primary zinc is very intensive regarding the energy demand and use of resources. The environmental impacts associated with the zinc production depend on the quality of the zinc ore mine, such as the presence of silver and lead that affects to ADP-elements. Other alternatives aimed at resource efficiency, such as zinc recovery from spent pickling baths that are being investigated in the LIFE2ACID project could provide a groundbreaking technology to reduce the environmental impacts associated to primary resource usage and waste treatment. Additionally, the CF derived from the production of redistilled and SHG zinc and paint coatings required to protect 1 m<sup>2</sup> of steel/y was compared using solvent paint and water-

based paint. The lowest CF corresponded to redistilled zinc (0.018 kg CO<sub>2</sub> eq./m<sup>2</sup> steel). The highest CF corresponds to solvent paint (0.040 kg CO<sub>2</sub> eq./m<sup>2</sup> steel), which is more reliable than water-based paint as anti-corrosion protection. This work confirms that the environmental assessment of individual HDG plants will help to set priorities in future improvements and will contribute to the sustainability of the galvanising sector by providing data for benchmarking.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.clet.2021.100041>.

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## The Gears & Wheels Behind Electric Forklift vs. Diesel Forklift

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- | Operational effectiveness
- | Sustainability goals
- | And bottom line

At Locators, we're committed to demystifying the complexities of this crucial decision. How? It's simple. We'll provide a detailed analysis of what makes each option unique. With decades of expertise, we understand the multitude of variables that businesses must balance. So, before investing in a solution, we offer you a deep dive into the operational details of electric and diesel forklifts.

The following covers everything from efficiency and maintenance to cost implications . . .

### EFFICIENCY

Electric forklifts have made enormous strides in the area of operational efficiency. A full battery can often last an entire eight-hour shift before recharging. This is enough to give you the needed run time without fueling interruptions. Diesel forklifts, on the other hand, excel in environments that demand heavy lifting and rugged durability. But, advancements in electric technology are blurring these lines. Some models offer equivalent or even superior lifting capabilities.

### MAINTENANCE

Electric forklifts generally offer the benefit of less routine maintenance. This is all thanks to fewer moving parts and no need for exhaust systems. Diesel forklifts, although robust, require regular servicing of filters, oils, and exhaust systems. These all add to the total cost of ownership. Thus, electric forklifts are emerging as the more straightforward, cleaner alternative. This is especially the case for businesses focused on minimizing operational hiccups.

### COST-EFFECTIVENESS

Electric forklifts frequently offer a better return on investment when considering long-term costs. While the upfront costs may be higher, savings on fuel and maintenance can result in a more cost-effective choice over time. Diesel forklifts, though cheaper initially, often become more expensive to operate. This is due to fuel costs and servicing — not to mention the potential for emission-related penalties.

The underlying mechanics and functionalities of forklifts are more than just technicalities. They are the key factors that align or misalign your equipment choices with your business objectives. As you weigh the pros and cons, you're not merely selecting a machine; you're shaping the future landscape of your operations. It's a decision that won't just impact your day-to-day activities. It'll also affect your long-term financial planning and environmental responsibilities. Locators bring this rich, detailed exploration to ease this pivotal decision-making process. Get in touch, and we can break down the electric forklift vs. diesel forklift options in an easily digestible manner. We're on hand to equip you with the valuable insights you need. Our ultimate goal is to ensure that you are not just making an informed choice but the right choice for your unique business needs. With us by your side, you're not just buying a piece of machinery. You're investing in an asset that complements your strategic direction.

**Propel your business into a future of efficiency, sustainability, and financial stability.**