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LPG Storage Facilities and the Seveso III Directive: Application of the Index Method and Verification of Territorial Compatibility

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Liquefied petroleum gas (LPG) storage facilities represent a significant share of major accident hazard establishments in Italy and fall under the Seveso III framework (Directive 2012/18/EU, implemented through Legislative Decree 105/2015). Despite the availability of the Italian index method established by the Ministerial Decree of 15 May 1996, no structured pathway has been articulated that connects index-based risk screening directly to territorial compatibility verification in a single, auditable workflow. This paper addresses that gap by demonstrating how the index method applies to upper-tier LPG facilities and by proposing a six-step operator-to-authority workflow for territorial compatibility checks. The method decomposes the plant into logical units, computes intrinsic risk indicators (fire, confined explosion, explosion in air, and general risk), and derives compensated indices that credit prevention and mitigation measures. A representative upper-tier case study—a 1,400-tonne facility with two underground tanks, pumping and compression equipment, and a truck loading bay—illustrates the full application and shows how credited safety measures shift all logical units into Category A. Credible accidental scenarios and conservative effect-distance modelling then feed the proposed workflow, yielding defensible planning inputs for land-use compatibility decisions. The results confirm that the index method, when applied with explicit auditability requirements and integrated with consequence modelling, provides a coherent and repeatable screening route from Safety Report obligations to territorial planning.

Keywords: LPG storage, Seveso III, major accident hazards, index method, Safety Report, land-use planning, territorial compatibility

1. Introduction

The European framework for the prevention and control of major accident hazards involving dangerous substances evolved from the Seveso accident of 1976 and culminated in Directive 2012/18/EU (Seveso III) [1]. In Italy, Seveso III is implemented through Legislative Decree No. 105 of 26 June 2015 [2]. LPG storage facilities represent a structurally significant subset of notified establishments: ISPRA data show that LPG sites account for approximately 25% of all major accident hazard (RIR) establishments registered in Italy [3], and a non-negligible fraction of these exceed the upper-tier threshold of 200 tonnes [2].

For upper-tier establishments, the Safety Report is the central regulatory instrument: it must demonstrate that major accident hazards have been identified, that safety measures are adequate, and that the claimed level of control is sustained over the plant lifecycle [1, 2]. In the Italian regulatory context, the Ministerial Decree of 15 May 1996 [4] provides a dedicated index method for LPG storage facilities and establishes reference thresholds for effect distances. After nearly three decades of regulatory practice, however, some recurring difficulties in applying the method have received limited attention in the open literature.

In practice, the method is rarely presented with the full set of auditability requirements that regulators expect—penalty factors, compensation credits, and the minimum verification evidence that makes compensated indices defensible under scrutiny. A separate and arguably more consequential difficulty concerns land-use planning. EU-level guidance documents describe how effect distances, vulnerability classes, and territorial categories are combined to support compatibility decisions [5–7], yet in Italian practice the bridge from a Safety Report to an actual compatibility determination has remained largely implicit. No structured, repeatable pathway has been articulated that connects index-based risk screening directly to the planning interface. While the individual components—index method, consequence modelling, land-use guidance—are well established in the literature [4, 6, 8], their integration into a single, auditable operator-to-authority workflow for LPG upper-tier facilities has not been previously formalised.

The aim of this paper is to address both difficulties. A six-step operator-to-authority workflow is proposed for territorial compatibility verification, integrating index-based risk screening with conservative consequence modelling to produce planning inputs that are auditable and consistent with both national [4] and European [6, 7] guidance. This workflow constitutes the primary methodological contribution of the paper: it translates existing regulatory instruments into a repeatable, documented sequence that an operator can follow and a competent authority can verify. The workflow is demonstrated on a representative upper-tier LPG facility of approximately 1,400 tonnes, with explicit attention to the auditability conditions that determine whether compensated indices remain credible across the plant lifecycle [9, 10]. The case study also serves to identify where the method is reliable and where its boundaries lie.

2. Safety Report Logic: From Major Accident Hazards to Planning Inputs

For upper-tier establishments, Seveso III requires a structured demonstration of major accident prevention and consequence limitation [1]. In practice, a Safety Report must accomplish three interrelated goals: operators must identify credible hazards and justify why they matter; they must show how hazards are controlled and how mitigation barriers prevent escalation or reduce impacts; and they must demonstrate that barrier performance is maintained through management systems and verification activities.

Experience from major hazard industries highlights that barrier effectiveness cannot be assumed and must be preserved through explicit integrity and governance processes [9, 10]. In the Italian context, accidental event analysis also feeds emergency planning and land-use planning documentation (e.g., the External Emergency Plan, or Piano di Emergenza Esterno, PEE). Land-use planning is not an "add-on": it is one of the operational interfaces of Seveso implementation, and guidance documents describe how effect distances, vulnerability, and territorial categories are combined to support compatibility decisions [6, 7]. The damage threshold values applicable to LPG facilities under the Ministerial Decree [4] are summarised in Table 1.

Table 1. Damage threshold values for LPG storage facilities (Ministerial Decree of 15 May 1996).

Scenario	Model	Thresholds / criteria
Fire	Thermal radiation (steady state)	12.5, 7, 5, 3 kW/m^2; structures/domino: 12.5 kW/m^2
BLEVE / Fireball	Thermal radiation (variable)	Fireball radius; 350, 200, 125 kW/m^2; reference distances: 100 m (tank park), 600 m (spheres), 800 m (cylinders)
Flash fire	Instantaneous criterion	LFL; $\frac{1}{2}$ LFL
UVCE	Overpressure	0.6 bar; 0.14, 0.07, 0.03 bar; structures/domino: 0.3 bar

3. LPG Storage Facilities: Configuration and Hazard Phenomenology

LPG is a mixture of light hydrocarbons, primarily propane and butane. Its ability to liquefy under moderate pressure enables compact storage but creates high-energy inventories: 1 litre of liquid generates approximately 250 litres of vapour, making even moderate releases capable of forming sizeable flammable clouds. An LPG storage facility falls under Seveso III when inventories exceed 50 tonnes (lower tier) or 200 tonnes (upper tier) [2]; ISPRA data show LPG sites represent approximately 25% of all notified establishments in Italy (Figure 1) [3].

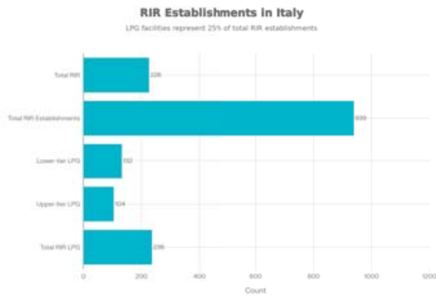

Fig. 1. Major accident hazard (RIR: *Rischio di Incidente Rilevante*) facilities in Italy involving LPG: distribution between lower-tier and upper-tier establishments. Total RIR and LPG subsets are shown; note that LPG facilities represent approximately 25% of all RIR establishments (source: ISPRA [3]).

Typical facilities comprise underground storage tanks, pumping and compression units, and truck loading bays. Each section presents distinct risk drivers: *frequency drivers*—the dominant mechanisms initiating loss of containment (e.g., coupling/uncoupling in transfer areas, seal degradation in pump rooms)—and *consequence drivers*—the factors governing release severity (e.g., large liquid inventories under pressure in storage tanks). This distinction is the physical basis for decomposing the plant into logical units for separate analysis, as prescribed by the Italian index method [4].

4. Accidental Event Analysis: Methods and Modelling Choices

Safety
Reports combine HAZOP, FMEA/FMECA, event tree analysis, and physical-effect modelling for consequence assessment. For LPG facilities, the index method provides structured screening of plant sections and a consistent mechanism for crediting prevention and mitigation measures; scenarios must be explicitly defined before index calculation begins, and modelling assumptions must be traceable to established physical-effects methods [11]. When impacts bear on land use, uncertainty treatment becomes essential [12]. Modern facilities rely on digital instrumentation—PLC-based ESD logic, networked gas detectors—that can fail through cyber-related pathways as well as mechanical degradation [13]; when compensated indices credit these layers, their availability must be treated as an operational property requiring governance.

5. Index Method of the Ministerial Decree of 15 May 1996

The Ministerial Decree of 15 May 1996 defines an index method aimed at categorizing LPG storage facilities according to major accident risk potential [4]. The method produces indices that support: (i) identification of critical logical units and dominant hazard type (fire vs. explosion), and (ii) evaluation of credited safety measures through intrinsic and compensated indices.

5.1. *Logical units and intrinsic indices*

The method begins with decomposition into logical units (and, if necessary, sub-units) assessed individually. Typical units include: STORAGE (fixed tanks), CYLINDERS (mobile containers), TRANSFER (loading/unloading), PUMPS (pumping/compression), and BOTTLING. Decomposition is not merely formal: transfer areas concentrate coupling and uncoupling operations and present higher human interaction frequency; pump/compressor areas concentrate rotating equipment and flanges; storage tanks concentrate inventory and escalation potential.

The method proceeds in two phases. Phase 1 computes intrinsic indices based on penalty factors associated with substance-specific risks, process characteristics, quantity, and layout. For LPG facilities, four intrinsic indices are used:

- Fire (F);
- Confined explosion (C);
- Explosion in air (A);
- General risk (G).

5.2. *Compensation factors and auditability*

Phase 2 applies compensation factors representing technical and organisational measures that reduce likelihood (prevention) and/or consequences (mitigation). Compensated indices F', C', A', and G'

are derived as $G' = G \times \prod_j c_j$, where each $c_j \in (0, 1]$ reflects a credited measure. The comparison between intrinsic and compensated indices is meaningful only if credited measures are verifiable.

Table 2 shows a worked numerical example for the PUMPS logical unit—the highest-risk unit in the case study ($G = 20{,}000$, Category D intrinsically). The DM 1996 defines penalty and compensation factor categories with admissible ranges; the values applied here are congruent with those ranges and representative of the described facility configuration—site-specific applications must derive values from actual operating conditions and verified barrier performance. Four penalty factors drive the intrinsic index: high inventory pressure ($p_1 = 2.5$), rotating equipment with flange-rich layout ($p_2 = 2.0$), absence of natural dilution ($p_3 = 1.6$), and elevated ignition potential from electrical equipment ($p_4 = 1.25$), giving $G = G_{\text{base}} \times p_1 \times p_2 \times p_3 \times p_4 = 2{,}000 \times 2.5 \times 2.0 \times 1.6 \times 1.25 = 20{,}000$. Four credited measures then reduce the index: passive fire protection ($c_1 = 0.5$), certified ESD on pump outlet ($c_2 = 0.4$), continuous gas detection with automatic isolation ($c_3 = 0.5$), and reinforced shielding ($c_4 = 0.5$), yielding $G' = 20{,}000 \times 0.5 \times 0.4 \times 0.5 \times 0.5 = 100$, i.e., Category A.

A recurrent issue in regulatory review is the auditability of inputs that generate the final indices. To keep the method traceable, each logical unit should be characterised through a minimum input set: (i) inventory and state (liquid/vapour, pressure/temperature range), (ii) equipment density and dominant failure interfaces (flanges, seals, couplings), (iii) ignition potential and local congestion, and (iv) separation distances and exposure to escalation. Practical experience in integrity management confirms that maintaining barrier availability requires explicit inspection and governance processes [9, 10].

Table 2. Worked index calculation for the PUMPS logical unit (aligned with DM 1996 factor structure).

Factor / measure	Value	Rationale / verification requirement
Penalty factors (intrinsic index, $G = 20{,}000$)		
High operating pressure	$p_1 = 2.5$	Liquid LPG at 6–8 bar
Rotating equip. + flanges	$p_2 = 2.0$	Dominant leak frequency drivers
Poor natural dilution	$p_3 = 1.6$	Enclosed pump room layout
Ignition sources	$p_4 = 1.25$	Electrical equipment class EEx
Compensation factors (compensated index, $G' = 100$)		
Passive fire protection	$c_1 = 0.50$	Inspection records, coating surveys
ESD on pump outlet	$c_2 = 0.40$	Annual functional test, IEC 61511
Gas detection + auto-isolation	$c_3 = 0.50$	6-month proof test, coverage map
Reinforced concrete shielding	$c_4 = 0.50$	Structural inspection, gap analysis
Result	$G' = 100$	**Category A** (≤ 100)

Table 3. General risk index categorization for logical units (Ministerial Decree of 15 May 1996).

General risk index (G or G')	Category
0–100	A
101–1100	B
1101–12500	C
>12500	D

6. Case Study: Upper-Tier LPG Storage Facility

A representative upper-tier LPG storage facility is considered: two underground tanks with a total capacity of approximately 1,400 tonnes, pumping and compression equipment, and a truck loading bay with multiple loading arms. Protective measures include passive fire protection, primary/secondary protection systems, gas detection, ESD, and reinforced concrete shielding between loading arms.

The facility is decomposed into three logical units: STORAGE, PUMPS, and TRANSFER. Category thresholds for the general risk index are recalled in Table 3. Intrinsic indices identify PUMPS as the most critical section ($G = 20{,}000$, Category D), consistent with the leak-frequency profile of rotating equipment and flange-rich layouts. The worked calculation for this unit is in Table 2; after applying compensation factors, all units reach Category A, yielding an overall Class I classification (Table 5). Barrier functions and verification evidence are in Table 4.

Table 4. Barrier functions, credited measures, and verification evidence (illustrative).

Barrier function	Credited measures	Verification evidence
Detection	Gas detection, alarms	Proof tests, coverage review, records
Isolation	ESD logic, remote valves	Functional tests, stroke tests, logs
Mitigation	Fireproofing, shielding, firefighting	Inspection, maintenance, drills
Containment	Integrity of piping/rotating equipment	RBI plan, inspection intervals, findings
Preparedness	Procedures, training, emergency response	Drill reports, KPIs, lessons learned

Table 5. Summary results of the index-based method applied to logical units.

Logical unit	Uncomp. G	Initial	Comp. G'	Final
STORAGE	6000	C	20	A
PUMPS	20000	D	100	A
TRANSFER	250	B	9	A

Operational implication. The numerical reduction from G to G' reflects the assumed performance of credited measures. A defensible claim requires that those barriers are maintained: proof testing, mechanical integrity, and emergency preparedness drills are what make the compensated indices credible over time [9, 10].

7. Accidental Scenarios and Territorial Compatibility

Territorial compatibility requires credible scenarios and their effect distances. For LPG facilities, dominant loss-of-containment initiators are transfer operations (hose/arm failures, vehicle impact), pump/compressor interfaces (seal degradation, flange leaks), and small-bore connections [5, 8]. Larger ruptures are less frequent but dominate consequence distances and remain relevant for conservative planning screening. Applicable damage thresholds are in Table 1; the assumption set is in Table 6.

Representative hole sizes anchor the two fire scenarios: 4-inch equivalent for jet fires; 1-inch for pool fires. Thermal radiation distances are computed using the TNO jet-fire and pool-fire models (Chapters 6 and 7 of PGS 2 [11]), applying the stated hole sizes, liquid-phase LPG release at storage pressure, and Pasquill stability class F/wind speed 1.5 m/s as the conservative atmospheric condition. Fireball distances follow the solid-flame model parameterisation reviewed in [14]. Three conservatism rules apply: (i) continuous release during the initial escalation window, (ii) no credit for immediate manual intervention, (iii) conservative atmospheric stability as stated above.

Table 6. Assumption set used for screening distances (conservatism basis and sensitivity by scenario type).

Assumption	Conservative intent	Sensitivity note
No immediate manual isolation	Avoid optimistic credit to operator action	Affects inventory released; minor on steady-state fire distances [4]
Representative hole sizes	Comparable screening across units	High for jet fire: distance $\propto \dot{m}^{0.4}$, $\dot{m} \propto d^2$ [11]
Conservative meteo stability	Larger footprints for vapour scenarios	Minor for fire scenarios; dominant for flash fire / UVCE [11]
No credit for early firefighting	Avoid optimistic mitigation timing	Relevant for pool growth; minor for jet-fire geometry
Steady-state radiation criteria	Direct mapping to decree thresholds	Consistent with DM 1996 threshold definitions [4]
Use of established effect models	Traceable, reviewable modelling basis	Model uncertainty discussed in [12, 14]

7.1. *Scenario screening and effect distances*

Within the index method, certain events may be excluded when units are Category A and adequate safety devices are present. For underground tanks, BLEVE scenarios are screened out under explicit protective conditions: full burial providing thermal shielding, limited likelihood of direct flame impingement, and reliable ESD arrangements [4]. The exclusion remains defensible only if the supporting conditions are explicitly stated and maintained. For the present facility, jet-fire scenarios provide the largest thermal radiation distances and constitute a conservative basis for compatibility screening; effect distances for all credible scenarios are reported in Table 8.

Table 7. From physical effects to planning zones (illustrative mapping for screening).

Zone	Criterion	Use in planning check
High impact	12.5 kW/m^2 or 0.3 bar	Conservative “domino/structure” screening
Medium impact	7–5 kW/m^2 or 0.14–0.07 bar	Vulnerable receptors screening
Low impact	3 kW/m^2 or 0.03 bar	Boundary of attention / sensitivity

7.2. *Land-use planning workflow (practical sequence)*

To make compatibility checks repeatable and auditable, the following workflow is proposed as a compact “operator-to-authority” interface. The mapping from physical-effect thresholds to planning zones is in Table 7; European guidance describes how these zones are combined with vulnerability classes and territorial categories [6, 7].

(1) **Define inputs:** inventories, operating envelope, layout, vulnerable receptors and territorial categories.
(2) **Define credible scenarios:** select representative initiators and sizes; justify screening/exclusions.
(3) **Model effects:** compute thermal radiation/overpressure footprints using traceable methods [11, 14].
(4) **Map to decree thresholds:** convert footprints into distances for each threshold (e.g., 12.5/7/5/3 kW/m^2) [4].
(5) **Overlay with land-use:** compare zones with territorial categories and vulnerable receptors using guidance logic [6, 7].
(6) **Conclude compatibility:** document outcome, residual sensitivities, and barrier conditions that preserve validity.

8. Discussion

The index method’s strength is practical consistency: plant segmentation, risk ranking, and structured crediting of safeguards in a repeatable, auditable argument [9, 10]. It is not a substitute for QRA when decisions require refined frequency modelling or societal risk metrics—it is best treated as a screening layer [11, 12].

Table 8. Credible accidental scenarios with approximate extension of damage areas (distances in m at listed thermal thresholds).

	JET FIRE (4” hole)				POOL FIRE (1” hole)			
Scenario	**12.5**	**7**	**5**	**3**	**12.5**	**7**	**5**	**3**
Accidental rupture — storage area	70	80	85	90	40	45	55	60
Accidental rupture — pump area	70	80	85	90	40	45	55	60
Compressor flange leak	20	23	25	27	–	–	–	–
Liquid-phase release — accidental rupture	70	80	85	90	45	50	53	58
Vapour-phase release — accidental rupture	25	30	33	38	–	–	–	–
Overpressure from tanker	20	30	35	45	30	35	40	45

The workflow proposed here differs deliberately from frequency-based LUP approaches such as Cozzani et al. [8], which integrate individual and societal risk contours with territorial vulnerability. The present workflow operates at the screening level using conservative consequence distances, executable from a completed index-based Safety Report without a full QRA. The trade-off—lower analytical precision for a repeatable, auditable process applicable to the large LPG upper-tier population—is explicit. The two approaches are complementary: this workflow identifies where escalation to probabilistic analysis is warranted [14].

8.1. *Sensitivity of territorial compatibility conclusions*

The effect distances in Table 8 rest on fixed conservative assumptions. Three parameters govern the dominant sensitivities, and their physical mechanisms differ [11]:

Hole size is the parameter with highest leverage on jet-fire distances. For a momentum-dominated jet fire, thermal radiation power scales with mass flowrate, which scales as d^2 for choked flow; radiation distance then scales approximately as $\dot{m}^{0.4}$ [11]. A 50% increase in equivalent hole diameter therefore increases jet-fire distances by roughly 30–40%, which is sufficient to shift planning zone boundaries and should be explicitly documented when compatibility margins are narrow.

Atmospheric stability has a minor effect on jet-fire and pool-fire distances, because thermal radiation from these scenarios is governed by flame geometry rather than atmospheric dispersion. Its influence is significant for vapour-cloud scenarios (flash fire, UVCE), where dispersion-driven cloud size is strongly stability-dependent

[11, 12].

Intervention timing has negligible effect on steady-state screening distances as computed here, because the damage threshold criteria in Table 1 are applied to the stationary release condition; the time to isolation affects inventory released but not the geometry of the established fire [4].

For overpressure scenarios, sensitivity to explosion yield fraction and confinement assumptions is an additional dominant source of uncertainty requiring site-specific analysis [11]. Incorporating explicit uncertainty bounds—through a two-point scenario set or first-order propagation—is methodologically feasible [12] but requires site-specific meteorological data and validated model error distributions beyond the scope of a screening assessment.

8.2. *Workflow applicability across facility types*

The workflow steps map onto the Safety Report structure required by Seveso III for any upper-tier establishment [1, 2]; only the logical unit decomposition changes between facility types (e.g., a sphere farm omits TRANSFER; a bottling installation adds CYLINDERS). The operator-to-authority interface logic—steps 1 through 6—is therefore invariant across LPG facility configurations within the DM 1996 applicability domain [4].

8.3. *Auditability deterioration over time*

Compensated indices reflect the barrier configuration at a point in time. Credited measures degrade in practice: ESD systems accumulate deferred maintenance, gas detector coverage changes with layout modifications, passive fire protection is damaged and not always reinstated. The implication for authorities is that compatibility determinations carry an implicit time condition: the barrier configuration assumed in the Safety Report must be periodically re-verified. A practical mechanism is to tie determinations to explicit *validity conditions*—a defined barrier set whose change triggers re-evaluation. Seveso III already requires a Safety Report update when significant changes occur [1, 2]; the proposed workflow formalises the link from that trigger to the planning interface [9, 10].

8.4. *Limitations*

The approach suits defensible screening when the facility is within the DM 1996 applicability domain and a conservative scenario set suffices for compatibility checks. It is not suited to contexts requiring societal risk contours or conditional escalation chains; there, the index method should indicate where a full QRA (Quantitative Risk Assessment) is needed. Credited automated protection layers depend on sustained availability—a joint technical and organisational property that extends to cyber-related degradation [13].

9. Conclusions

This paper addressed two connected difficulties in applying the Italian index method to upper-tier LPG facilities: the lack of explicit documentation of how intrinsic and compensated indices are built up from penalty and compensation factors, and the absence of a structured, repeatable pathway connecting Safety Report outputs to territorial compatibility decisions.

On the first point, the worked numerical example for the PUMPS logical unit (Table 2) demonstrates the full calculation chain. The intrinsic index $G = 20{,}000$ (Category D) reflects four penalty factors: high operating pressure, rotating equipment with a flange-rich layout, poor natural dilution, and ignition potential. Four credited measures—passive fire protection, certified ESD, continuous gas detection, and reinforced shielding—each tied to defined verification activities, reduce the index to $G' = 100$ (Category A). The numerical outcome is defensible only if those barrier functions are actively maintained: proof testing, mechanical integrity programmes, and emergency preparedness drills are not optional.

On the second point, the six-step operator-to-authority workflow (Section 7.2) provides a repeatable, auditable interface from Safety Report to compatibility determination, consistent with DM 1996 thresholds [4] and European land-use planning guidance [6, 7]. Applied to the 1,400-tonne case study, jet-fire scenarios dominate compatibility screening, with thermal radiation distances from 70 m at 12.5 kW/m^2 to 90 m at 3 kW/m^2. Hole size is the dominant sensitivity parameter: a 50% increase in equivalent diameter shifts distances by approximately 30–40% [11]. The workflow structure is invariant across LPG facility types within the DM 1996 domain [1, 4]; only the logical unit decomposition changes with configuration. Two governance implications follow: compatibility determinations carry an implicit time condition (barrier degradation invalidates the basis unless re-verified, with the Seveso III Safety Report update obligation providing the regulatory hook), and credited instrumented protection requires governance against cyber-related as well as mechanical degradation [13].

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