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Regulatory Archaeology of Environmental Assessment: Encoding Static Axioms into Law and Moving Towards Regime-Aware Decision Frameworks

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> *This article belongs to the research program "Waste as dynamical systems" (Piens, in preparation). Its sections are numbered independently; the few §x.y references not resolved in the text point to the companion articles, namely the theoretical Manifesto (axioms S1 to S4, theorems T1 to T4), the anaerobic digester, the toxicology of emerging contaminants, environmental logistics and the ecology of critical transitions, or to the book-length manuscript.*

Abstract

Assessors and regulators decide on single numbers: a score, a threshold, a credit. When the assessed system holds several regimes, these numbers are not merely uncertain but locally meaningless, and the decision they carry is ill-founded. We first show *where* the four axioms of static evaluation (S1 to S4, established in the companion manifesto) are encoded in law, namely REACH, CLP, EN 15804, the European Waste List and USEtox, not by negligence but by administrability: knowing which axiom a text encodes tells you in advance the class of wastes it will misjudge. We then propose regime-aware assessment. An *unpredictability gauge* at the head of the report aggregates sub-scores (proximity to a bifurcation, type of nonlinearity, medium horizon, data regime) into a position from green to red; and when the unit does not exist, three regime-matched frameworks apply: minimax for severe irreversible tipping, info-gap robustness for an acceptability zone to widen, and adaptive management where monitoring is feasible and action reversible. A worked case, a digester operated near its fold, yields three distinct and rational set-points. Regime diagnosis does not oppose the texts; it marks where regulatory reading must be completed by a dynamical one. Choosing the wrong framework, such as expected utility on a bistable system, is not imprecision but a category error.

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1. Introduction

A regulation needs frozen classes and constant factors: this is the condition of its administrability at scale. But this convenience has a price, and that price is paid by the decisions made where the assessed system will not be frozen. This article starts from a diagnosis, the four implicit axioms of static evaluation, point estimation (S1), linear characterization (S2), path independence (S3) and categorical invariance (S4), established and proved in the companion manifesto; it then shows where they are inscribed in law, then what one can do, concretely, to decide when the unit does not exist. We recall only that these axioms, reasonable in their domain of origin, become false for precise classes of waste, and that the output of a non-linear system is a *regime*, a qualitatively distinct operating state, and not a noisy quantity.

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2. Regulatory archaeology: where the axioms are engraved

The four axioms are not only habits of calculation: they are inscribed in law and in standards, and this is what explains why their fractures recur with such regularity. They are not local errors that a more careful practitioner would correct; they are structural choices, engraved upstream of him. To run through the texts that govern assessment is to find our four axioms one by one.

The REACH regulation (EC 1907/2006) organizes all European chemical knowledge *by substance*: a CAS number, a dossier, a hazard profile deemed valid for all uses and all physical states. This is categorical invariance (S4) erected into a principle of registration. And the safety demonstration it requires (showing that exposure stays below derived no-effect levels, the DNELs) further assumes a monotonic dose-response (S2): for an endocrine disruptor with a non-monotonic response, a DNEL calibrated on high doses can certify "no effect" a low-dose regime that does produce one (§7.2). Two axioms for the price of one.

The CLP regulation (EC 1272/2008), which classifies and labels, proceeds by dichotomous categories founded on intrinsic properties: a substance is category-1 carcinogenic, or it is not. This is again S4, and it is S1 (point estimation) in another form, a threshold per category. Asbestos bound in a matrix and asbestos released as fibers receive the same class there, although the whole difference of exposure is there: the nomenclature has no way to encode that the hazard depends on form.

The EN 15804 standard, which governs the environmental declarations of construction products, aggregates impacts linearly, by constant factors, and credits module D (the avoided material or energy) with a fixed amount, independent of the state of the system that receives this flow. This is linear characterization (S2) and path independence (S3) inscribed in the accounting itself. A digester near washout (§7.5) keeps, on paper, its methane credit, even as it is becoming a source.

The European waste list (Decision 2000/532/EC) assigns each flow a fixed code and class (hazardous or not), independent of the storage context. This is S4 at the scale of wastes: there exists no category "inert in mass, mobile in fines," so that the contextual reclassification of §7.4 quite simply has no box to be entered in.

The USEtox model, finally, which supplies the toxicity characterization factors, summarizes each substance by a single linear factor aggregating ecotoxicity, persistence and bioaccumulation. This is S2 and S1 joined in a single number. It can, by construction, encode neither non-monotonicity (§7.2), nor mobility commanded by redox (§7.8), nor the fact that a PFAS threshold falls by four orders of magnitude in six years (§7.1).

These choices do not stem from ignorance. They make the system administrable on a very large scale and transfer the burden of proof to the declarant: "respect the threshold, you are covered." A regulation, in this, resembles the gauge of a railway track: once the rails are laid, everything must run at that width, and a reality cut otherwise quite simply cannot circulate. The price of this convenience is that non-linearity is placed literally out of frame, invisible, hence irremediable, as long as the nomenclature offers no place for regime.

This archaeology has a direct use, and it is thus that it must be used: to know the axiom a text encodes is to know in advance the class of wastes it will judge badly. Where a decision rests on REACH or USEtox, one knows to beware of substances with a non-monotonic response; where it rests on the waste list or on CLP, of materials whose hazard depends on form; where it rests on EN 15804, of processes liable to shift regime. Regime diagnosis does not oppose these texts: it indicates, for each, the precise point where the regulatory reading must be completed by a dynamical one.

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3. Methodological consequence: assess the regime, not only the quantity

The constructive proposal follows directly from the diagnosis. Where the static apparatus hides uncertainty in a margin or a threshold, a *regime-aware* assessment does the opposite: it reports, beside the number, the regime the system occupies. Are we in a monotonic or non-monotonic response? a bounded or heavy-tailed distribution? a single state or a bistability? far from a bifurcation, or very near? This is not one more piece of information drowned in the report; it is the key that says *how to read the number*, with what confidence, and over what horizon.

An unpredictability gauge. To make this signal legible without burdening practice, we propose to append it to the report as a gauge: a single cursor on a colored scale, to be placed at the head of the document, beside the main result, as one affixes a confidence index. It does not replace the number and does not claim to correct it; it frames it, saying: *here, the result is as predictable as the data allow*; or, on the contrary: *here, one should first improve the data, and if one cannot, improve the predictivity of the result before turning it into a decision*. Concretely, rather than a single number, two are presented (the result and its regime), and it is their gap that situates the study in a reasonable zone or not. It plays the role of a dashboard warning light: it does not drive in the practitioner's place, but it tells him when to ease off.

The gauge aggregates a few sub-scores that this article has already all introduced, which makes it reproducible and not arbitrary. The first is the **proximity to a bifurcation**: is the treated system, like the digester of §7.5 or the lake of §7.9, liable to occupy two regimes, and is one operating near the fold? The early-warning signals (§7.6) give the measure of it. The second is the **type of non-linearity** at play, that is, the axiom (S1 to S4) most exposed; a non-monotonic response, a contextual speciation or a heavy tail do not weigh in the same way. The third is the **medium horizon**, the exponent λ_{max} of §5.2: an atmospheric or fingered-soil contaminant inherits a short horizon. The fourth is the **regime of the data** itself, the quality score and its coupling, in the sense of the companion preprint. From these sub-scores a position on three bands is deduced: at **green**, a stable and predictable regime, where standard LCA and its log-normal margin suffice; at **amber**, a transition zone, where the result is recommended to be paired with warning signals and a sensitivity analysis; at **red**, a bistable or chaotic regime near a tipping point, where the number alone must not carry the decision, which then falls to the frameworks of §4.

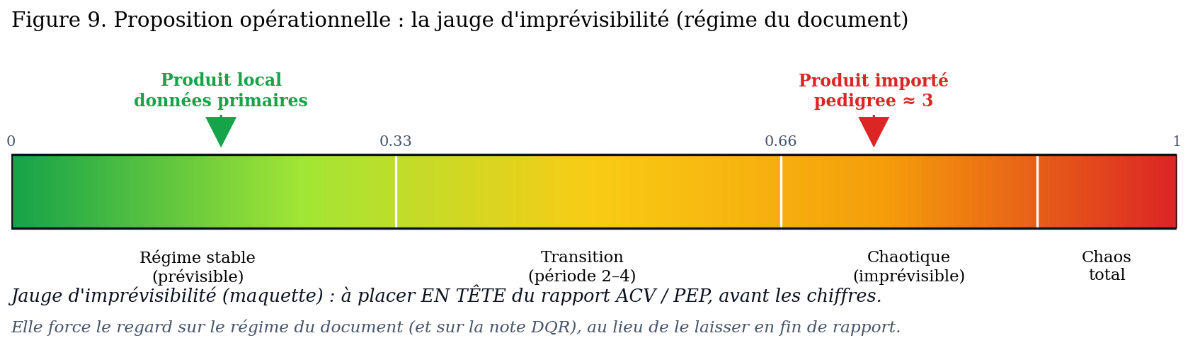

Figure 9. Mock-up of the unpredictability gauge: from green (stable, predictable regime) to amber (transition) then red (near a tipping point, chaotic). The cursor is placed at the head of the report, beside the result. Example: an imported product informed by medium-quality data slides toward the transition zone, where a well-characterized local product stays at green.

It remains to say how a practitioner uses it without breaking the existing accounting, for that is the condition of its adoption. The gauge modifies no regulatory calculation: it is added on the opening page, like an overhaul of the data quality score that, instead of reducing to a score, would also say *what type* of uncertainty it is. A practitioner who integrates this reading from the outset does not change his inventories; he changes the questions he asks. Faced with a digester, he checks the distance to the fold before claiming a credit; faced with a product whose use depends on a volatile factor, the electricity of a luminaire (§1.1), he reports a regime range rather than a point; faced with a waste whose hazard depends on form, he tests the leaching regime of the real storage context (§7.4) instead of content alone. And he can present all this to an auditor without offending the standard, since he has retracted nothing: he has only added, beside the required number, the information that says whether or not it can be trusted.

3.1 Classification of wastes by regime, not by category alone

The unpredictability of a waste depends not so much on its *nature* as on its *containment* and its *context*. The same inert waste has, in principle, a low unpredictability rate; but that rate depends in reality on the framework that protects it, the mode of storage, the logistics that transports it, the environment that receives it and the climate sensitivity of the area. An inert stored in the open air, beside ultimate wastes, under an aggressive climate, does not occupy the same regime as the same inert in sealed containment. At the other extreme, a whole vineyard falls under a very high unpredictability even with good tools and good data, because there the relevant "framework" is the *framing itself*, the extent one agrees to analyze and the escape routes one chooses to ignore.

This is why we propose, in complement to the regulatory classification, a regime reading grid: for each major family of wastes, what is the factor that triggers the switch (wetting, anaerobiosis, mechanical disturbance, climate change) and what level of unpredictability results. Appendix A gives a first version, conceived as the seed of a more ambitious instrument: a portfolio of molecules and categories, indexed by regime, that we sketch at the close.

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4. Deciding when the unit does not exist

When the output of a system is bimodal (T2), classical expected utility deceives: its mean falls into the valley the system never occupies. To decide under a non-linear regime demands other criteria, chosen according to the regime diagnosed in part I.

Minimax, guarantee the worst case. One chooses the action that minimizes the worst possible consequence. Relevant when the tipping is irreversible and the consequence grave: size a digester far from the fold, over-contain a persistent compound (TCDD) whatever the redox scenario envisaged. Cost: an over-sizing. Benefit: no catastrophic branch is reachable.

Robustness (info-gap, Ben-Haim 2006). One fixes a satisfaction threshold (energy credit ≥ X, dose ≤ Y) then maximizes the amplitude of uncertainty tolerated without violating it. Relevant when there exists an acceptability zone to widen, for example keeping an exposure below the peak of a non-monotonic curve (§7.2).

Adaptive management (Williams 2011). One acts, one observes signals, including the early-warning signals of §7.6, then one corrects. Relevant when monitoring is possible and the action reversible: soils with variable redox (§7.8) monitored by Eh probes, the load of a digester adjusted on the rise in variance of the volatile fatty acids. Inoperative for long latencies (TCDD), where the warning would arrive too late.

Diagnosed regime	Violated axiom	Reversibility	Approach
Bistable, grave tipping	S1, S3	no	**minimax**
Non-monotonic dose-response	S2	yes	**info-gap**
Context-dependent, monitoring feasible	S4	partial	**adaptive**
Persistent multi-compartment	S3, S4	no	**minimax** + future generations

A worked, quantified case makes the choice concrete. Take again the digester of §7.5, whose fold is at $D_{fold} \approx 0.587\ d^{-1}$, and suppose its real load fluctuates by ±25 % around the set-point, a medium data quality, on the order of a DQR of 3. At what nominal load should it be operated? Naive expected utility answers "as close as possible to the fold," to maximize throughput and hence the mean methane credit; this is precisely the trap of T2, for very near the fold the output is bimodal and the mean describes no real state. The three frameworks give three distinct answers, all rational. **Minimax** demands that no scenario provoke washout: in the worst case, the real load rises by 25 % *and* a cold snap lowers the fold by about 15 % (toward 0.50 d^{-1}); one then needs $D_{nominal} \times 1.25 \leq 0.50$, that is $D \leq 0.40\ d^{-1}$, a throughput cut by a third, but no tipping reachable. **Info-gap** aims to stay a net sink while maximizing the amplitude of tolerated fluctuation: to be robust to 35 % variation (beyond the 25 % expected), one sets $D_{nominal} = 0.587 / 1.35 \approx 0.43\ d^{-1}$, a little more throughput than minimax, at the price of vulnerability to extreme fluctuations only. **Adaptive management**, finally, operates at $D \approx 0.50\ d^{-1}$ (as close as possible to the fold) but monitors the return time τ (the rise in variance of the volatile fatty acids, §7.6) and reduces the load as soon as the warning signal lights up; it captures the maximal throughput, at the price of online sensors and reversibility of action. Three set-points (0.40, 0.43, 0.50 d^{-1}), a single system: the choice bears not on the precision of a number, but on the posture one adopts before an irreversible tipping.

One can see these three frameworks as three temperaments before the same cliff. Minimax steps back until it never again risks the fall; info-gap approaches the edge keeping a safe margin; adaptive management advances with its eyes on the void, ready to step back at the first dizziness. None is wrong in the absolute; each suits a kind of precipice, and the whole art consists in knowing, thanks to the diagnosis, before which precipice one stands.

Regime diagnosis is therefore not an academic refinement: it selects the decision framework. To choose the wrong framework (to apply expected utility to a bistable system) is not an imprecision, it is a category error.

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5. Conclusion

Environmental assessment sometimes forces the assessor to err, not by incompetence but because its founding texts have engraved axioms that non-linear reality contradicts. One does not repair this with a supplement of data: no accumulation of measurements corrects a false assumption. One repairs it by making the regime visible, through an unpredictability gauge that says how to read the number, and through decision frameworks (minimax, info-gap, adaptive management) chosen according to the diagnosed regime rather than according to a mean that, near a tipping point, describes no real state. These tools retract nothing from existing accounting; they add, beside the required number, the information that says whether or not it can be trusted. This is all an assessor can honestly offer to those who will live downstream of his reports: not the promise that nothing will tip, but the clarity to know where to look, and the composure to do so in time.

Appendix. A portfolio of regimes: wastes, molecules and their switches

This appendix is the seed of a larger instrument. We conceive it as the first page of a future portfolio, an open database that would index molecules and waste categories by their dynamical regime, their critical axiom and their tipping trigger, in the manner of a directory to consult before any assessment. The grid below fixes its format; its extended version, much fuller, will be the subject of dedicated work.

The logic is that of §3.1: the unpredictability of a flow lies less in its nature than in its containment and its context. Each row therefore associates, with a waste family or a molecule, the regime it can occupy, the axiom it defeats, the factor that triggers its switch, the resulting level of unpredictability and the vignette that treats it.

Family / molecule	**Dominant regime**	**Critical axiom**	**Tipping trigger**	**Unpredictability**	**Vignette**
Inert C&D (heap, covered)	fixed point	(none)	(none)	**low**	n/a
Inert C&D (fines)	class switch	S4	acid leaching, wetting	**medium → high**	§7.4
Gypsum / plaster	acidification	S4, S3	landfill anaerobiosis (H_2S)	**high**	§7.4
Fly ash (fluorine)	HF speciation	S4	pH < 4 + reactive silica	**medium → high**	§7.4
Digestate / biogas	process bistability	S1, S3	load near the fold	**medium**	§7.5
PFOA / PFAS	heavy tail, moving threshold	S1, S4	toxicological revision, accumulation	**high**	§7.1
Endocrine disruptors (BPA)	non-monotonic dose-response	S2	low-dose exposure	**high**	§7.2
Arsenic (soils)	redox switch	S4	aeration ↔ saturation (Eh)	**high**	§7.8
Thiamethoxam (neonicotinoid)	population bifurcation	S2	colony loss threshold	**high**	§7.7
Phosphorus (leachate → lake)	eutrophication hysteresis	S3	crossing the load threshold	**high (irreversible)**	§7.9
TCDD (dioxin)	lipophilic persistence, multi-compartment	S3, S4	water-table fluctuation, food chain	**very high**	§8.1
Asbestos (bound)	fixed point… until rupture	S4	mechanical disturbance	**low → very high**	§7.4
Asbestos (friable) / fibers	fiber regime	S4	suspension	**very high**	§7.4
Nanotubes (long)	fiber analogy	S4	(poorly characterized)	**unknown** (to watch)	companion manifesto

The format is deliberately homogeneous with the diagnosis of the companion manifesto and the gauge of §3: in time, each portfolio entry would also carry its position on the unpredictability gauge, so that a practitioner could, from the framing of a study, read the probable regime of a flow before computing the slightest impact.

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Supplement

Code and figures are reproducible (Python; numpy/scipy/matplotlib) and openly deposited (Zenodo DOI at the first stable version). The factors quoted are not cherry-picked points but representative values over a plausible parameter space, with robustness sweeps.